Identifying Research Needs in Support of Regulatory Aspects of the Aquaculture Framework Agreement

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by

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ABSTRACT

Keizer, P.D. and Zurbrigg, R. 2007. Identifying Research Needs in Support of Regulatory Aspects of the Aquaculture Framework Agreement. Ca. Tech. Rep. Fish. Aquat. Sci. 2751: vii +78 p

A framework is presented for the identification of priorities for research in support of the regulatory aspects of the Aquaculture Framework Agreement that is under development by the Canadian Council of Fisheries and Aquaculture Ministers. The proposed framework is based on the risk analysis of the hazards associated with aquaculture. The analysis is limited to the risks as defined by published information on the severity and probability of occurrence of undesirable outcomes. Recent comprehensive peer reviews of the scientific literature are used as the knowledge base. The analysis can be readily updated when additional knowledge is available. The framework is generally applicable and could be used to include the socioeconomic and political risks in the analysis.

RÉSUMÉ

Keizer, P.D. and Zurbrigg, R. 2007. Identifying Research Needs in Support of Regulatory Aspects of the Aquaculture Framework Agreement. Ca. Tech. Rep. Fish. Aquat. Sci. 2751: vii + 78 p

Nous présentons un cadre d'identification des priorités de recherche en appui des aspects réglementaires de l'Entente cadre sur l'aquaculture en voie d'être élaborée par le Conseil canadien des ministres des Pêches et de l'Aquaculture. Le cadre proposé se fonde sur une analyse du risque que posent les dangers de l'aquaculture. L'analyse se limite aux risques tels que définis dans des documents publiés sur la gravité des conséquences indésirables et la probabilité qu'elles se produisent. Les résultats de récentes analyses exhaustives par les pairs des ouvrages scientifiques portant sur le sujet ont servi à établir la base des connaissances. L'analyse du risque peut facilement être mise à jour lorsque de nouvelles données sont publiées. Le cadre étant d'application générale, les risques sur les plans socioéconomique et stratégique peuvent être inclus dans l'analyse.

EXECUTIVE SUMMARY

A framework employing risk analysis is presented to identify research needs to support the regulatory aspects of the Aquaculture Framework Agreement being developed by the Aquaculture Task Group (ATG) of the Canadian Council of Fisheries and Aquaculture Ministers. This framework is based on the identification of environmental risks associated with the operation of aquaculture facilities. The identification of risks is based upon the most recent scientific reviews. Research needs are identified where empirical or theoretical risks are perceived to exist. The research identified is required either to reduce scientific uncertainty or to identify management actions that can mitigate potential effects. The proposed framework has wide applicability and the analysis can be readily revised as current information is corrected or updated or as new information becomes available.

It is important to note that the scope of this paper is limited to scientific research needs related to the regulatory aspects of aquaculture. A parallel exercise is being conducted for the ATG evaluating the research needs to support the development and commercialization of aquaculture. There will be some overlap between these two documents and likely some apparent disagreement. There are instances where a research need is clearly a low priority from a regulatory or scientific perspective but has a higher priority from a socioeconomic or industry development perspective. This apparent disagreement is not unexpected and is actually desirable since it clearly identifies the driving force and hence the potential funding source for the research activity.

There will be an apparent focus on the sea cage culture of Atlantic salmon simply because it is the Canadian aquaculture activity for which considerable knowledge concerning its interactions with the environment is available. The analysis contained herein, with a few exceptions, also applies to the culture of coho and chinook salmon on the west coast. The developed framework has also been applied to the culture of freshwater finfish in cages and shellfish culture.

Environmental interactions with aquaculture industry activities can result in environmental changes that can be summarized into several major categories:[3]

- nutrient enrichment: the release of uneaten food, feces, pseudo-feces, and dissolved metabolites to sediment and water column.
- chemical pollution: related primarily to release of therapeutic chemicals used in the treatment of disease and parasitic infections; also includes inorganic contaminants from feed, etc.
- habitat change and loss: changes in seabed, lake, or river bottom habitat due to the accumulation of organic matter; also includes the loss of habitat due to conversion of coastal land and wetland.

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[3] Based on a list from Hambrey and Southall (2002) except for the separation of disease and parasites as a distinct category. This list is similar to that provided in ICES (2005).

- changes in wild fish and shellfish populations: the escape and interbreeding of farmed and wild fish and the competition of escaped farm fish for prey and habitat.
- introduction of disease and parasites: introduction of exotic species (including disease and parasites); increased abundance of pathogens in the water derived from farmed stock

The undesirable or unacceptable end points associated with these risks are identified, a qualitative risk analysis is performed, and research needs, including monitoring needs, are identified for those end points where the risk of occurrence is unacceptable. A summary of the identified end points and research needs by category follows.

MARINE FINFISH CULTURE (SALMON)

This paper focuses on environmental interactions relating to salmon net cage culture identified by the extensive scientific knowledge on that activity. However research is being directed at the development of a number of other marine finfish species for aquaculture. It is likely that the risks associated with the culture of other marine finfish species will be similar to those for salmon culture. Nutrient enrichment from feed and excretion, chemical pollution from intentional and unintentional discharges, changes in habitat and wild fish populations, and disease concerns will all have to be addressed. Depending upon the particular species being cultured and the details of the culture activity, the nature of these hazards will vary. However it is important to be proactive in identifying the research necessary for effective management of the risks.

NUTRIENT ENRICHMENT

End point: Enhancement of macrophyte production affecting other human activities

Research needs: Identification of far-field effects is hampered by the lack of baseline data and high natural variability. Potential changes can be mitigated through site selection, e.g., limits on total production in embayments where nutrients may accumulate. Research priority is low since severity is low and the probability of occurrence is moderate to low. Mitigation is available.

Monitoring needs: Pre-development data and annual surveys of peak macroalgal production. Trend over time data is an invaluable scientific research and adaptive management resource.

End point: Increase in frequency, distribution, and nature of algal blooms affecting human activities or resulting in toxicity to humans and/or wild and cultured organisms

Research needs: Effective experimental design to study potential changes is confounded by high natural variability coupled with a lack of definitive knowledge of the conditions

that are necessary and sufficient to generate nuisance blooms. Nutrient loading has been mitigated by changes in food formulation and better food conversion ratios, however metabolic nutrient excretion cannot be effectively reduced. The severity of the change would be rated as low to negligible and the probability of occurrence is considered low to extremely low; therefore the research priority is low.[4]

Monitoring needs: Monitoring of coastal plankton populations at local and regional scales can provide information that is useful for site selection and for site management to reduce potential effects on the industry from harmful algal blooms. Trend over time data is an invaluable scientific research and adaptive management resource.

Chemical Pollution

End point: Releases, accidental and approved, of chemicals to aquaculture sites result in environmental levels that are toxic to native flora and fauna.

Research needs: In general, only rarely has there been a demonstration of sub-lethal chronic effects at the population level of contaminants in the marine environment. Therefore severity of the potential effect would be rated as low since they are likely to be expressed only at a local level. The probability of occurrence is at most low and possibly extremely low. The priority for research is rated low, however a mass balance model of area-wide inputs of chemicals of concern would clarify the analysis of the risk for specific locations.

Monitoring needs: Temporal trend data for a select group of priority pollutants in one or more environmental compartments would provide useful information for industry and integrated management decisions. Trend over time data is an invaluable scientific research and adaptive management resource.

Habitat Change and Loss

End point: Enrichment of bottom sediments near cages with fine sediment and organic matter resulting in changes in benthic community structure.

Research needs: The changes will be localized therefore the severity of the change is low; however the probability of occurrence is high. Mitigation is available through informed site selection coupled with good management practices. This includes consideration of essential habitat for any species at risk since even a localized change of such habitat would be considered unacceptable under the Federal Species at Risk Act. In general, the research priority would be rated medium. However validation of deposition models is required to ensure that advice on site selection is reliable. Research is also needed to understand the density factor: how many farms in an embayment are too many?

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[4] From an industry development perspective the research priority is likely higher due to the economic impact HABs have on the industry.

Monitoring needs: Monitoring of benthic conditions under cages coupled with data on site operations such as feed conversion rates, growth rates, mortalities, disease, parasites, etc. would provide the basis for much-needed science advice on site selection and best management practices. Trend over time data is an invaluable scientific research and adaptive management resource.

End point: Reduction of water-dissolved oxygen concentration to levels that are stressful or lethal to fish

Research needs: From an ecosystem perspective, the severity is extremely low. However from a fish farmer's perspective the effect can be severe. Given good site selection and the use of best business practices the potential occurrence is extremely low. The cause and effects relationships are well known and the occurrence of these events is predictable. Research priority is low.

Monitoring needs: Dissolved oxygen is a potential indicator for environmental change at erosional sites where any changes are more likely to be expressed in water column components of the ecosystem than in benthic components. Trend over time data is an invaluable scientific research and adaptive management resource.

End point: Changes in the currents and physical habitat affecting resident organisms

Research needs: The severity effects on organisms due the alteration of physical habitat from aquaculture activities are deemed to be low or negligible because of the limited geographical extent and its temporary nature. There is a potential for more serious changes, but these can be readily mitigated through proper site selection. The probability of occurrence is high in the absence of informed site selection, but low with proper site selection practices. The overall assessment is that this is an acceptable risk. No priority research is identified.

Monitoring needs: No requirements.

CHANGES IN WILD FISH POPULATIONS

End point: Significant decline in survival of wild salmon due to genetic changes resulting from interbreeding with cultured conspecifics.

Research needs: The severity of the potential change is moderate to high. Where a stock is listed by COSEWIC as an endangered species, the change would be rated as catastrophic. There is however a wide range of scientific opinion on the probability of occurrence ranging from low to high. Continued research activity is a high priority. The challenge will be to identify research activities that will significantly reduce the uncertainty regarding either the severity of the potential changes or the probability of the change being expressed.

Monitoring needs: Monitoring the number of escapees, and the occurrence of escapees and their progeny in the wild will provide an indication of the potential scale of the problem.

End point: Changes in the abundance of endemic trophic resources at the population level

Research needs: The severity of the change is low or negligible and the probability of the change being expressed is low. Research needs are therefore rated as low. It should be noted that for this hazard, scale is an important factor: extensive developments in enclosed areas represent a greater hazard with greater potential severity and probability of occurrence.

Monitoring needs: None identified.

End point: Competition between escaped cultured fish and native fish for essential habitat results in reduced fitness or competitive displacement of the native species.

Research needs: There is considerable uncertainty regarding both the severity of this hazard and its potential for occurrence. Of particular concern would be competition with either food or habitat for any species at risk. The potential severity ranges from low to catastrophic and the probability of the change being expressed ranges from negligible to high. Research to reduce the uncertainty is a high priority, but success will be confounded by complexity of interactions and high natural variability.

Monitoring needs: Monitoring of the number and location of escapees and monitoring the occurrence of escaped fish and habitat for species at risk could be an effective research and management tool.

INTRODUCTION OF PATHOGENS

End point: An exotic aquatic animal disease regulated by federal legislation is introduced and/or transferred into a previously disease-free site/zone/naïve population, resulting in significant resource, economic and/or trade-related losses.

Research needs (partnerships implicit): Research priority is high as consequence of severity is considered high and the probability of occurrence is moderate. Mitigation is limited. Ongoing, targeted development/improvement of diagnostic testing is needed to optimize scope, ease of use, timeliness, integrity, accuracy, specificity, sensitivity, and cost-effectiveness (e.g., rapid tests, microarrays, pathogen characterization, biosecurity safeguards, international reference test design). Ongoing, targeted research of occurrence, epidemiology, pathogenesis and pathology of federally regulated exotic aquatic animal pathogens/diseases is also a priority.

Monitoring/control needs: Statistically valid and internationally accepted exotic disease surveillance/monitoring and sound sampling/testing are required to bolster baseline, exposure, and occurrence data.

End point: A severe enzootic aquatic animal disease (AAD), not governed regionally by federal field control measures but of "named" concern to a province/territory, becomes epizootic and/or exceeds regulatory/husbandry tolerances, in/near regional

sites/zones/populations with a potential for significant resource, economic and/or trade-related losses.

Research needs (partnerships implicit): Research priority is high as consequence of severity of change is considered high and the probability of occurrence is deemed moderate to high. Mitigation is achievable but costly. Ongoing, targeted development/improvement of diagnostic testing is required to optimize scope, ease of use, timeliness, integrity, accuracy, specificity, sensitivity, and cost-effectiveness (e.g., rapid tests, microarrays, pathogen characterization, biosecurity safeguards, reference test design). Ongoing, targeted research is needed on the occurrence, epidemiology, pathogenesis, and pathology of severe enzootic and exotic AADs.

Monitoring/control needs: Statistically valid AAD monitoring and sound sampling/testing are required to bolster baseline, exposure and occurrence data.

End point: An unregulated enzootic aquatic animal disease (AAD) outbreak causes variable degrees of resource/economic loss to local watersheds and/or aquaculture sites, but poses little risk for further spread and/or unlimited persistence.

Research needs (partnerships implicit): Research priority is medium as consequence of severity is rated medium (albeit localized) and the probability of occurrence is moderate. Mitigation is achievable, but may be compromised by multiple antibiotic resistance, making disease prevention the research focus. Ongoing, targeted research to provide accurate on-farm rapid diagnostic testing is needed. Also research to better understand the growth characteristics, vulnerabilities and epidemiology of local aquatic animal disease (LAAD) pathogens is required (to strengthen LAAD preventive measures related to human activities, biosecurity, and aquaculture husbandry practices as well as helping improve disease treatment regimes).

Monitoring/control needs: Statistically valid LAAD monitoring and sound sampling/testing are required to bolster baseline, exposure, and occurrence data.

BIVALVE CULTURE

Environmental risks posed by bivalve aquaculture are generally quite different from those associated with finfish culture. Cultured bivalves feed on the natural supplies of seston in the water; man-made feed is not provided. However, in areas of intense shellfish culture the hazards may be similar to those associated with finfish culture. Nutrient dynamics are changed by the feeding and excretion of large numbers of filter feeders. Feces and pseudo-feces build up at culture sites changing benthic habitat and effecting natural benthic communities. In coastal areas this fine particulate material can sequester and concentrate pollutants entering the ecosystem by various pathways. The effects of intensive bivalve culture on ecosystem structure and dynamics at the "bay" level are not well understood. Disease and the effect of exotic species are proving to be important concerns for the development of sustainable shellfish culture.

A DFO National Advisory Process meeting on bivalve culture was held in Moncton, NB the week of 27 February 2006. The following analysis is based largely on the Science Advisory Report and Research documents for that meeting.

Nutrient Enrichment

End point: Excretion of nutrients by large numbers of cultured bivalves affects inorganic nutrient cycling resulting in changes to ecosystem components and functions.

Research needs: The severity of the potential change ranges from negligible to high and the probability of an adverse outcome being expressed is largely unknown. Relative scale is critical. The research priority is therefore judged to be moderate. Research should focus on case studies where undesired outcomes are most likely to occur to reduce uncertainty in predicting both the potential severity and likelihood of occurrence.

Monitoring needs: Systematic long-term monitoring of environmental indicators is essential to the detection of shifts in ecosystem function and /or structure. Monitoring programs have to be established to support research initiatives.

Habitat Change and Loss

End point: Enrichment of bottom sediments near shellfish farms with fine sediment and organic matter resulting in change in benthic community structure.

Research needs: The severity of the potential change ranges from negligible to high and the probability of an adverse outcome being expressed is largely unknown. Relative scale is critical. The research priority is therefore judged to be moderate. Research should focus on case studies where undesired outcomes are most likely to occur to reduce uncertainty in predicting both the potential severity and likelihood of occurrence. Development and validation of predictive models is essential to the support of informed management decisions.

Monitoring needs: In such situations where environmental quality targets are unknown, monitoring key indicators for trend over time is essential for making informed management and regulatory decisions.

End point: Changes in the currents and physical habitat resulting in increased occurrence and abundance of undesirable organisms.

Research needs: When the scale of the bivalve culture activity is large relative to the ecosystem or system of interest, there is legitimate concern about the potential severity of this effect. There is little or no knowledge about the factors that affect either the severity or potential for occurrence. The further development of ecosystem models is essential to increasing our knowledge and our ability to predict. Mitigation can be achieved by keeping the scale of the aquaculture activity small relative to the size of the ecosystem, yet more knowledge is needed regarding scaling factors and appropriate management targets. The research priority is moderate.

Monitoring needs: Monitoring of appropriate benthic and pelagic indicators is essential for increasing our understanding of these effects and for making informed management decisions.

Changes in Wild Fish and Shellfish Populations

End point: Changes in the abundance of endemic trophic resources at the population level.

Research needs: As noted earlier, relative scale is very important. Hence, severity of change could range from negligible to high but there is very little knowledge upon which to base predictions. The potential for occurrence is also largely unknown. The priority for research is therefore moderate to high, particularly where there is pressure to permit aquaculture operations of relatively large scale. Due to the complex nature of the interactions, modeling will be an essential component of the required research activity.

Monitoring needs: Monitoring key ecosystem indicators is essential for trend over time analysis, particularly where reference points and targets are not available.

Introduction of Pathogens

The research/monitoring needs already identified for marine finfish culture are broadly applicable to shellfish aquaculture. However, the open, exposed nature of bivalve molluscan aquaculture differs from most finfish aquaculture regimes to the extent that risks and research needs are highly focused on epidemiology, including sub-clinical infections, and differential diagnostics (particularly of protozoan pathogens) to underpin monitoring, surveillance, zonation, disease control, biosecurity and, especially, integrated management. Disease interactions relating to containment and escapement (as in finfish cage culture) are non sequiturs here.

FRESHWATER CAGE CULTURE

Cage culture in lakes presents hazards similar to those related to sea cage culture, but the potential changes are quite often modified by environmental factors as well as the scale of the operations relative to the freshwater ecosystems. The knowledge base, particularly for Canada, for freshwater finfish cage culture is relatively small compared with that for salmon sea cage culture. The few recent studies that have been reported indicate that changes as a result of nutrient enrichment have been reduced greatly compared to earlier studies. However much is unknown about the other identified hazards.

Nutrient Enrichment

End point: Increase in frequency, distribution, and nature of algal blooms affecting wild or cultured organisms, including potential toxicity to humans and/or wild and cultured organisms, effects on human activities and the use of freshwater as a commodity.

Research needs: The scale of environmental changes resulting from fish cage operations in water basins can range from local to basin wide, therefore the severity of the changes can range from low to high, with the probability of the change being expressed is probably moderate. However there is a lack of knowledge about the long-term fate of nutrients, especially phosphorus in particulate wastes. The research priority is generally moderate as a result of a high degree of uncertainty regarding severity and occurrence. The priority for research on the fate of nutrients in particulate wastes is also moderate.

Monitoring needs: Since there are limited recent data available, monitoring of primary production, algal community composition, or biomass changes in the vicinity of any major freshwater aquaculture activity would provide useful information.

Chemical Pollution

End point: Releases, accidental and approved, of chemicals to aquaculture sites result in environmental levels that are toxic to native flora and fauna.

Research needs: Section 36 of the Fisheries Act prohibits the discharge of any deleterious substance into waters frequented by fish, therefore although the potential severity of such a discharge is high, particularly in smaller lakes, the probability of occurrence is extremely low or negligible. The need for research related specifically to aquaculture inputs is low. However, as noted in the introduction to this section, there is little information available on freshwater aquaculture in general so there is a priority for research to at least establish the scope of the problem.

Habitat Change and Loss

End point: Enrichment of bottom sediments near cages with fine sediment and organic matter resulting in changes in benthic community structure and function

Research needs: Due to the localized nature of the enrichment, the severity of the potential change is rated as low although the probability of the enrichment being expressed is high. Predictive models need to be validated for freshwater systems so that their efficacy for site selection and management can be confirmed. Research priority is moderate.

End point: Reduction of water-dissolved oxygen concentration to levels that are stressful or lethal to fish

Research needs: There is considerable uncertainty whether or not fish farms contribute significantly to the oxygen depletion in lakes. The severity of the potential change is high but there is uncertainty about the likelihood that the effect would be expressed. The research need is therefore moderate.

End point: Changes in the currents and physical habitat effecting resident organisms

Research needs: The potential changes are highly localized and therefore severity is considered low. The likelihood that the changes will be expressed is moderate. Research

needs are essentially the same as those directed at understanding the effects of altering fish habitat and identifying appropriate compensatory actions. Research priority is low.

Changes in Wild Fish Populations

End point: Changes in the abundance of endemic trophic resources at the population level

Research needs: The severity of the change is low or negligible and the probability of the effect being expressed is low in situations where waste loading is small relative to ecosystem size and retention time. Research needs are therefore rated as low. However given the paucity of information for freshwater finfish culture in Canada, research activity is warranted to provide basic information.

End point: Significant decline in survival of native fish as a result of genetic changes resulting from interbreeding with cultured organisms or competitive displacement.

Research needs: The severity of the potential change is low since the only species to be affected is an introduced species. There is however a wide range of opinion on the probability of occurrence ranging from low to high. There is also a great deal of uncertainty about both the severity and occurrence. While research priority is moderate to high, the challenge will be to identify research activities that will significantly reduce the uncertainty regarding either the severity of the potential changes or the probability of the effects being expressed.

Monitoring needs: Monitoring the number of escapees and the occurrence of escapees and their progeny in the wild will provide an indication of the potential scale of the problem.

Introduction of Pathogens

The points above regarding the introduction of pathogens to marine finfish are wholly applicable to freshwater finfish aquaculture.

RESEARCH IN SUPPORT OF REGULATORY NEEDS

The framework presented here provides an objective means for identifying research priorities at the program level.[5] As the industry changes or new information becomes available, the framework can be readily applied to reassess priorities. Projects submitted for approval within these research priorities should undergo a cost benefit analysis to further refine the priorities.

Effective progress on these research needs can only be made in a stable research environment. Because of the high degree of variability in natural systems, most research

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[5] "Program level" is synonymous with "hazard level," i.e. is research required to reduce uncertainty or identify mitigation for a particular hazard? Hazards are activities or results of activities that can potentially disrupt ecosystem structure or function.

will require 2 to 3 years of field observations followed by data analysis and interpretation. In other areas significant progress can only be made through long-term monitoring projects that require cooperative agreements with other levels of government, the industry, and possibly other stakeholders.

SOMMMAIRE

Le présent cadre d'analyse du risque a été élaboré dans le but d'identifier les besoins en matière de recherche en appui des aspects réglementaires de l'Entente cadre sur l'aquaculture en voie d'âtre élaborée par le Groupe de travail sur l'aquaculture (GTA) du Conseil canadien des ministres des Pêches et de l'Aquaculture. Le cadre repose sur l'identification des risques pour l'environnement reliés à l'exploitation d'installations aquacoles et l'identification de ceux-ci, sur les plus récents examens scientifiques. Les besoins en matière de recherche sont identifiés lorsque des risques empiriques ou théoriques sont perçus comme existants. Ces recherches sont requises pour soit réduire l'incertitude scientifique ou identifier les mesures de gestion qui peuvent permettre d'atténuer les effets potentiels. Le cadre proposé a une application étendue, et l'analyse peut être facilement révisée à mesure que les données disponibles sont rectifiées ou mises à jour ou que de nouvelles données sont publiées.

Il est important de prendre note que la portée du cadre se limite aux besoins en matière de recherche scientifique reliés aux aspects réglementaires de l'aquaculture. Une évaluation en parallèle des besoins en matière de recherche en appui du développement et de la commercialisation de l'aquaculture est en voie d'être menée pour le GTA. Il y aura chevauchement entre les deux documents et probablement un certain niveau de désaccord apparent. Il existe des cas où un besoin en matière de recherche sera clairement une priorité faible du point de vue réglementaire ou scientifique mais de priorité élevée du point de vue socioéconomique ou du développement de l'industrie. Ce désaccord apparent n'est pas inattendu; il est désirable en fait, car il permet d'identifier clairement l'élément moteur et donc la source potentielle de financement de l'activité de recherche en question.

L'accent semble mis en apparence sur l'élevage du saumon atlantique en cages en mer simplement parce qu'elle est l'activité aquacole pratiquée au Canada pour laquelle nous disposons de beaucoup de connaissances concernant ses interactions avec le milieu. L'analyse présentée, à quelques exceptions près, s'applique également à l'élevage du saumon coho et du saumon quinnat sur la côte Ouest. Le cadre a également été appliqué à l'élevage de poissons en cages en eau douce et à la culture de bivalves.

Les interactions entre l'environnement et les activités de l'industrie de l'aquaculture peuvent entraîner des modifications de l'environnement, qui peuvent être divisées en plusieurs grandes catégories :[6]

- enrichissement en matières nutritives : conséquence du rejet de restes d'aliments, de fèces, de pseudofèces ou de métabolites dissous dans les sédiments ou la colonne d'eau;

[6] D'après une liste tirée de Hambrey et Southall (2002), sauf pour la classification des maladies et des parasites dans une catégorie distincte. Cette liste est semblable à celle présentée dans ICES (2005).

- pollution chimique : principalement le résultat du rejet de produits chimiques thérapeutiques utilisés dans le traitement de maladies et d'infections parasitaires, ainsi que des contaminants inorganiques provenant des aliments, etc.;
- modification et perte d'habitat : changements dans l'habitat du fond de la mer, d'un lac ou d'un cours d'eau dus à l'accumulation de matières organiques, y compris la perte d'habitat due à la conversion du littoral et des milieux humides;
- changements dans les populations sauvages de poissons, de mollusques et de crustacés : résultat de l'évasion de poissons d'élevage, de l'accouplement de ceux-ci avec des poissons sauvages et de la compétition exercée par les évadés pour des proies et des parcelles d'habitat;
- introduction de maladies et de parasites : introduction d'espèces exotiques (y compris des maladies et des parasites); abondance accrue d'agents pathogènes dans la colonne d'eau attribuable aux stocks d'élevage.

Les conséquences indésirables ou inacceptables associées à ces risques sont identifiées, une analyse qualitative des risques est effectuée et les besoins en matière de recherche, y compris les besoins en matière de surveillance, sont établis pour les conséquences dont le risque qu'elles se produisent est inacceptable. Un résumé des conséquences établies et des besoins en matière de recherche par catégorie suit.

ÉLEVAGE DE POISSONS EN MER (SAUMON)

Ce document porte principalement sur les interactions entre l'environnement et les élevages de saumons en cages identifiées dans les nombreuses études scientifiques de cette activité. Cependant, des recherches ciblées sont en cours sur le développement d'un certain nombre d'autres espèces de poissons marins aux fins d'élevage. Il est probable que les risques reliés à l'élevage d'autres espèces de poissons marins seront semblables à ceux que comporte l'élevage du saumon. L'enrichissement en matières nutritives attribuable au rejet de restes d'aliments et de matières fécales, la pollution chimique résultant de déversements accidentels ou intentionnels de produits chimiques dans l'eau, les modifications de l'habitat et les changements dans les populations de poissons sauvages et les préoccupations que soulève la transmission de maladies devront être étudiés. La nature de ces dangers variera selon l'espèce mise en élevage et les particularités de l'activité d'élevage. Il est toutefois important d'être proactif dans la détermination des recherches à effectuer pour assurer la gestion efficace des risques.

ENRICHISSEMENT EN MATIÈRES NUTRITIVES

Conséquence : Accroissement de la production de macrophytes nuisant à des activités humaines

Besoins en matière de recherche : L'absence de données de base et la forte variabilité naturelle de la production de macrophytes entravent l'identification des effets à distance. Le choix d'un site approprié pour lequel, par exemple, des limites de production totale dans les enfoncements de côte où les matières nutritives peuvent s'accumuler sont fixées, peut permettre d'atténuer les changements potentiels. La priorité en matière de recherche

est faible étant donné que le niveau de gravité de cet effet est bas et que la probabilité qu'il se produise est modérée à faible. Des mesures d'atténuation sont disponibles.

Besoins en matière de surveillance : Recueillir des données avant le développement d'un site aquacole et effectuer des relevés annuels de la production maximale de macroalgues. Des données sur les tendances temporelles constituent une ressource de très grande valeur pour la recherche scientifique et la gestion adaptative.

Conséquence : Accroissement de la fréquence, de la distribution et de la nature des poussées d'algues nuisibles aux activités humaines ou toxiques pour l'homme et/ou des organismes sauvages et d'élevage.

Besoins en matière de recherche : Les protocoles expérimentaux pour l'étude des changements potentiels sont rendus confus par la forte variabilité naturelle des poussées d'algues nuisibles et l'absence de connaissances définitives des conditions nécessaires et suffisantes pour les produire. Bien que des changements dans la formulation des aliments et de meilleurs taux de conversion alimentaire aient permis de réduire la charge en matières nutritives, le volume de déchets métaboliques excrétés ne peut cependant pas être réduit de façon efficace. La gravité de l'effet est classée comme faible à négligeable. La probabilité qu'il se produise étant considérée comme faible à extrêmement faible, la priorité de recherche est donc faible.[7]

Besoins en matière de surveillance : La surveillance des populations côtières de plancton aux échelles locale et régionale peut être une source d'information utile pour le choix et la gestion d'un site aquacole afin de réduire les effets potentiels des poussées d'algues nuisibles sur l'industrie. Des données sur les tendances temporelles constituent une ressource de très grande valeur pour la recherche scientifique et la gestion adaptative.

POLLUTION CHIMIQUE

Conséquence : Les rejets, accidentels ou approuvés, de produits chimiques dans les eaux des sites aquacoles aboutissent à des niveaux de ces produits dans l'environnement qui sont toxiques pour la faune et la flore indigènes.

Besoins en matière de recherche : En général, des effets sublétaux chroniques des contaminants à l'échelle des populations ont rarement été démontrés dans le milieu marin. La gravité des effets potentiels est donc classée comme faible étant donné qu'ils ne seraient probablement décelés qu'au niveau local. La probabilité qu'ils se produisent est tout au plus faible et peut-être extrêmement faible. La priorité de recherche est considérée comme faible; cependant, un modèle de bilan massique des apports de produits chimiques préoccupants dans un espace géographique permettrait de clarifier l'analyse du risque pour des emplacements déterminés.

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[7] Du point de vue du développement de l'industrie, la priorité de recherche est probablement plus élevée en raison de l'incidence économique des poussées d'algues nuisibles sur l'industrie.

Besoins en matière de surveillance : Des données sur les tendances temporelles pour un groupe choisi de polluants prioritaires dans un compartiment environnemental ou plus permettraient à l'industrie de prendre des décisions au titre de la gestion intégrée. Des données sur les tendances temporelles constituent une ressource de très grande valeur pour la recherche scientifique et la gestion adaptative.

MODIFICATION ET PERTE D'HABITAT

Conséquence : Enrichissement, en sédiments fins et en matières organiques, des sédiments du fond près des cages entraînant des changements dans la structure de la communauté benthique.

Besoins en matière de recherche : Étant donné que la modification de l'habitat sera localisée, sa gravité sera faible. Par contre, la probabilité que cet effet se produise est élevée. Les effets peuvent être atténués par le choix éclairé des sites aquacoles et de bonnes pratiques de gestion. Ceci comprend la considération de l'habitat essentiel de toute espèce en péril car même une modification localisée de cet habitat serait considérée comme inacceptable en vertu de la *Loi sur les espèces en péril* du gouvernement fédéral. En général, la priorité de recherche est classée comme moyenne. Les modèles de dépôt doivent toutefois être validés afin d'assurer que les conseils donnés au titre du choix des sites sont fiables. Des recherches sont également requises afin de comprendre le facteur de densité, à savoir quand le nombre de fermes installées dans un enfoncement de côte est excessif.

Besoins en matière de surveillance : La surveillance des conditions du milieu benthique sous les cages et des données sur les activités d'élevage, tels les taux de conversion alimentaire, les taux de croissance, les taux de mortalité, les maladies, les parasites, etc., serviraient de fondement aux avis scientifiques indispensables pour le choix des sites et des meilleures pratiques de gestion. Des données sur les tendances temporelles constituent une ressource de très grande valeur pour la recherche scientifique et la gestion adaptative.

Conséquence : Réduction de la teneur en oxygène dissous jusqu'à des niveaux stressants ou létaux pour les poissons.

Besoins en matière de recherche : Du point de vue écosystémique, la gravité de cet effet est extrêmement faible. Toutefois, du point de vue des pisciculteurs, l'effet peut être grave. Si le site a été bien choisi et que les meilleures pratiques de gestion sont appliquées, la probabilité qu'il se produise est extrêmement faible. Les relations de cause à effet sont bien connues, et la survenance de ces évènements est prévisible. La priorité en matière de recherche est faible.

Besoins en matière de surveillance : La teneur en oxygène dissous est un indicateur potentiel d'une modification de l'environnent à un site d'érosion où toute modification est plus susceptible de se manifester dans les composantes de la colonne d'eau de l'écosystème que dans les composantes benthiques. Des données sur les tendances

temporelles constituent une ressource de très grande valeur pour la recherche scientifique et la gestion adaptative.

Conséquence : Changements dans les courants et modification de l'habitat physique nuisant aux organismes résidants.

Besoins en matière de recherche : La gravité des effets sur les organismes résultant de la modification de l'habitat physique attribuable aux activités aquacoles est considérée comme faible à négligeable à cause de l'étendue géographique limitée et de la nature temporaire de ces effets. Des changements plus graves peuvent se produire, mais ils peuvent être facilement atténués par le biais du choix d'un site adéquat. La probabilité que ces effets se produisent est élevée en l'absence du choix éclairé de site, mais faible s'il l'est. En général, le risque est acceptable. Aucune priorité de recherche n'a été établie.

Besoins en matière de surveillance : Aucun.

CHANGEMENTS DANS LES POPULATIONS DE POISSONS SAUVAGES

Conséquence : Baisse appréciable de la survie des saumons sauvages résultant de changements génétiques entraînés par l'accouplement avec des congénères d'élevage.

Besoins en matière de recherche : La gravité de l'effet potentiel est modérée à élevée. Lorsqu'un stock est inscrit à la liste des espèces en voie de disparition du COSEPAC, le changement est classé comme catastrophique. Toutefois, les opinions scientifiques concernant la probabilité qu'il se produise varient énormément; elles la situent de faible à élevée. La poursuite des recherches est une priorité élevée. Le défi sera d'identifier les activités de recherche qui permettront de nettement réduire l'incertitude qui entoure la gravité des changements potentiels et la probabilité qu'ils se produisent.

Besoins en matière de surveillance : La surveillance du nombre et de la présence d'évadés, ainsi que de leur progéniture, dans le milieu sauvage donnera une idée de l'ampleur potentielle du problème.

Conséquence : Changements dans l'abondance de ressources trophiques endémiques au niveau de populations.

Besoins en matière de recherche : La gravité de l'effet est faible ou négligeable et la probabilité qu'il se produise, faible. Les besoins en matière de recherche sont donc considérés comme faibles. Il faudrait prendre note que, dans le cas de ce danger, l'échelle représente un facteur important : la présence d'un grand nombre de fermes dans des eaux abritées constitue un plus grand danger, de gravité et de probabilité de survenance potentiellement plus élevées.

Besoins en matière de surveillance : Aucun identifié.

Conséquence : La compétition entre les poissons d'élevage évadés et les poissons indigènes pour l'habitat essentiel entraîne une diminution de la condition physique ou le déplacement par compétition d'espèces indigènes.

Besoins en matière de recherche : Il existe une grande part d'incertitude concernant la gravité de ce danger et la possibilité qu'il se produise. La compétition avec des espèces en péril pour la nourriture ou l'habitat serait particulièrement inquiétante. La gravité potentielle de l'effet va de faible à catastrophique et la probabilité qu'il se produise, de négligeable à élevée. La recherche en vue de réduire l'incertitude est une priorité élevée, mais son succès sera rendu confus par la complexité des interactions et la forte variabilité naturelle de celles-ci.

Besoins en matière de surveillance : La surveillance du nombre d'évadés et de leur présence, ainsi que de l'habitat des espèces en péril, pourrait constituer un outil de recherche et de gestion efficace.

Introduction d'agents pathogènes

Conséquence : Une maladie d'animaux aquatiques exotiques réglementée par la législation fédérale est introduite et/ou transmise dans une zone, une population indigène ou un site exempt de cette maladie, résultant en d'importantes pertes financières, pertes liées à la ressource et/ou pertes liées au commerce.

Besoins en matière de recherche (partenariats implicites) : La priorité de recherche est élevée parce que la gravité de l'effet est considérée élevée et la probabilité qu'il se produise, modérée. Les possibilités d'atténuation sont limitées. Des travaux ciblés de développement et de perfectionnement des tests diagnostiques sont requis afin d'optimiser leur portée, facilité d'emploi, opportunité, intégrité, précision, spécificité, sensibilité et rentabilité (p. ex. épreuves de dépistage rapide, biopuces, caractérisation des agents pathogènes, mesures de biosécurité, conception des essais d'évaluation de la référence internationale). Des recherches ciblées de longue durée sur la survenue, l'épidémiologie, la pathogénie et la pathologie des agents pathogènes/des maladies d'animaux aquatiques exotiques, réglementés par la législation fédérale, sont également une priorité.

Besoins en matière de surveillance et de lutte : La surveillance et le contrôle, statistiquement valides et reconnus internationalement, des maladies exotiques, ainsi que des plans d'échantillonnage et de dépistage robustes, sont requis pour bonifier les données de base, les données d'exposition à ces maladies et les données de survenue de celles-ci.

Conséquence : Une grave maladie enzootique d'animaux aquatiques, non assujettie au niveau régional à des mesures fédérales de contrôle sur le terrain mais reconnue comme préoccupante dans une province ou un territoire, devient épizootique et/ou atteint un niveau d'activité qui dépasse les tolérances réglementaires/d'élevage dans/près d'un site/zone/population, résultant en d'importantes pertes financières, pertes liées à la ressource et/ou pertes liées au commerce.

Besoins en matière de recherche (partenariats implicites) : La priorité de recherche est élevée parce que la gravité de l'effet est considérée comme élevée et la probabilité qu'il se produise, modérée à élevée. L'atténuation est possible mais coûteuse. Des travaux ciblés de développement et de perfectionnement des tests de diagnostic sont requis afin d'optimiser leur portée, facilité d'emploi, opportunité, intégrité, précision, spécificité, sensibilité et rentabilité (p. ex. épreuves de dépistage rapide, biopuces, caractérisation des agents pathogènes, mesures de biosécurité, conception des essais d'évaluation de la référence internationale). Des recherches ciblées de longue durée sur la survenue, l'épidémiologie, la pathogénie et la pathologie des graves maladies des animaux aquatiques exotiques et enzootiques sont également une priorité.

Besoins en matière de surveillance et de lutte : La surveillance statistiquement valide, ainsi que des plans d'échantillonnage et de dépistage robustes, des maladies des animaux aquatiques sont requis pour bonifier les données de base, les données d'exposition à ces maladies et les données de survenue de celles-ci.

Conséquence : Une flambée d'une maladie enzootique non réglementée chez des animaux aquatiques cause des niveaux variables de pertes financières et de pertes de ressources au niveau des bassins versants locaux et/or des sites d'aquaculture, mais pose peu de risque de propagation et/ou de persistance.

Besoins en matière de recherche (partenariats implicites) : La priorité de recherche est moyenne parce que la gravité de l'effet est considérée comme moyenne (quoique localisée) et la probabilité qu'il se produise, modérée. L'atténuation est possible, mais la multirésistance aux antibiotiques peut la compromettre. La prévention des maladies enzootiques doit donc être la cible des recherches. Des recherches ciblées de longue durée portant sur le développement d'épreuves précises de dépistage rapide dans les fermes sont également requises, ainsi que des recherches qui permettront de mieux comprendre les caractéristiques de croissance, les faiblesses et l'épidémiologie des agents pathogènes locaux d'animaux aquatiques (pour renforcer les mesures de prévention des maladies locales d'animaux aquatiques reliées aux activités humaines, à la biosécurité et aux pratiques d'élevage aquacole, ainsi qu'à améliorer les régimes de traitement des maladies).

Besoins en matière de surveillance et de lutte : La surveillance statistiquement valide, ainsi que des plans d'échantillonnage et de dépistage robustes, des maladies locales des animaux aquatiques sont requis pour bonifier les données de base, les données d'exposition à ces maladies et les données de survenue de celles-ci.

CULTURE DE BIVALVES

Les risques pour l'environnement que pose la culture de bivalves sont généralement assez différents de ceux reliés à l'élevage de poissons. Les bivalves de culture se nourrissent du seston présent naturellement dans la colonne d'eau; aucun apport en aliments fabriqués n'est fait. Toutefois, dans les régions où se pratique la culture intensive de bivalves, les dangers peuvent être semblables à ceux reliés à l'élevage de poissons. La prise d'aliments par un grand nombre d'organismes filtreurs et

l'excrétion de fèces et de pseudofèces entraînent la modification de la dynamique des matières nutritives. Les fèces et les pseudofèces s'accumulent aux sites de culture, ce qui résulte en des modifications de l'habitat benthique et des effets sur les communautés benthiques naturelles. Dans les régions côtières, ces fines particules peuvent absorber et concentrer les polluants qui entrent dans l'écosystème par diverses voies. Les effets de la culture intensive de bivalves sur la structure et la dynamique de l'écosystème au niveau des baies sont mal compris. Les maladies et l'incidence d'espèces exotiques se révèlent d'importantes préoccupations pour le développement de la conchyliculture durable.

Une réunion du Processus consultatif national du MPO portant sur la culture des bivalves a eu lieu à Moncton, au Nouveau-Brunswick, pendant la semaine du 27 février 2006. L'analyse suivante s'articule en grande partie autour de l'Avis scientifique et des documents de recherche préparés pour cette réunion.

Enrichissement en matières nutritives

Conséquence : Le volume de matières nutritives excrétées par un grand nombre de bivalves de culture nuit au cycle des matières nutritives inorganiques, ce qui entraîne des changements dans les composantes et les fonctions de l'écosystème.

Besoins en matière de recherche : La gravité du changement potentiel va de négligeable à élevée alors que la probabilité qu'un effet indésirable se produise est en grande partie inconnue. L'échelle relative est critique. La priorité de recherche est donc considérée comme modérée. Les recherches devraient être centrées sur des études de cas lorsque des effets indésirables sont plus susceptibles de se produire afin de réduire l'incertitude concernant la prévision de la gravité potentielle des effets et la probabilité qu'ils se produisent.

Besoins en matière de surveillance : La surveillance systématique à long terme d'indicateurs environnementaux est essentielle au dépistage de changements dans la fonction et/ou la structure de l'écosystème. Des programmes de surveillance doivent être mis sur pied en appui des initiatives de recherche.

Modification et perte d'habitat

Conséquence : Enrichissement, en sédiments fins et en matière organique, des sédiments de fond près des fermes conchylicoles entraînant un changement dans la structure de la communauté benthique.

Besoins en matière de recherche : La gravité du changement potentiel va de négligeable à élevée alors que la probabilité qu'un effet indésirable se produise est en grande partie inconnue. L'échelle relative est critique. La priorité de recherche est donc considérée comme modérée. Les recherches devraient être centrées sur des études de cas lorsque des effets indésirables sont plus susceptibles de se produire afin de réduire l'incertitude concernant la prévision de la gravité potentielle des effets et la probabilité qu'ils se produisent. Il est essentiel que des modèles de prévision soient élaborés et validés en appui de la prise de décisions de gestion éclairées.

Besoins en matière de surveillance : Lorsque les cibles de qualité environnementale sont inconnues, la surveillance d'indicateurs clés en vue d'établir les tendances temporelles est essentielle à la prise de décisions éclairées en matière de gestion et de réglementation.

Conséquence : Changements dans les courants et modification de l'habitat physique entraînant la présence et l'abondance accrues d'organismes indésirables.

Besoins en matière de recherche : Lorsque l'échelle de l'activité de culture de bivalves est grande par rapport à l'écosystème ou le système en question, la gravité potentielle de ces effets est une préoccupation légitime. La connaissance des facteurs qui agissent sur leur gravité ou le potentiel qu'ils se produisent est minime sinon nulle. Les modèles d'écosystème doivent être peaufinés afin d'améliorer notre connaissance et notre capacité de prévision de ces effets. Ceux-ci peuvent être atténués par le maintien de l'activité conchylicole à une petite échelle par rapport à la taille de l'écosystème, mais une meilleure compréhension des facteurs d'échelle et des cibles de gestion appropriées est requise. La priorité de recherche est modérée.

Besoins en matière de surveillance : La surveillance d'indicateurs benthiques et pélagiques appropriés est essentielle pour améliorer notre compréhension des effets et prendre des décisions de gestion éclairées.

Changements dans les populations sauvages de poissons, de mollusques et de crustacés

Conséquence : Changement dans l'abondance des ressources trophiques endémiques au niveau de populations.

Besoins en matière de recherche : Comme il l'a été indiqué ci-dessus, l'échelle relative est très importante. La gravité du changement peut donc aller de négligeable à élevée, mais nous disposons de très peu de connaissances sur lesquelles nous pouvons fonder nos prévisions. La probabilité que cet effet se produise est également en grande partie inconnue. La priorité de recherche est par conséquent modérée à élevée, en particulier lorsque des pressions sont faites afin que des activités aquacoles d'échelle relativement grande soient autorisées. À cause de la nature complexe des interactions, la modélisation constituera un élément essentiel de l'activité de recherche requise.

Besoins en matière de surveillance : La surveillance d'indicateurs écosystémiques clés est essentielle pour l'analyse des tendances temporelles, en particulier lorsque des points de référence et des cibles n'ont pas été établis.

Introduction d'agents pathogènes

Les besoins en matière de recherche et de surveillance identifiés pour l'élevage de poissons en mer s'appliquent d'une façon générale à la culture de bivalves. Toutefois, la nature ouverte et exposée de la conchyliculture diffère de la plupart des régimes d'élevage de poissons dans la mesure que les risques et les besoins en matière de recherche sont hautement centrés sur l'épidémiologie, y compris les infections subcliniques et les diagnostics différentiels (en particulier des protozoaires pathogènes)

pour étayer le contrôle, la surveillance, la zonation, la lutte contre les maladies, la biosécurité et, en particulier, la gestion intégrée. Les interactions entre les maladies reliées au confinement et à l'évasion (comme dans le cas de l'élevage de poissons en cages) ne s'appliquent pas dans ce cas-ci.

ÉLEVAGE EN CAGES EN EAU DOUCE

L'élevage de poissons en cages dans des lacs présente des dangers semblables à ceux reliés à l'élevage en cages en mer, mais les changements potentiels sont assez souvent modifiés par des facteurs environnementaux ainsi que l'échelle des installations par rapport aux écosystèmes d'eau douce. La base de connaissances, en particulier en ce qui concerne le Canada, sur l'élevage de poissons en cages en eau douce est relativement petite en comparaison de la base de connaissances sur l'élevage du saumon en cages en mer. Les quelques récentes études qui ont été diffusées révèlent que les changements résultant de l'enrichissement en matières nutritives sont nettement moindres en comparaison de ce qui a été signalé dans des études antérieures. Toutefois, on ignore encore beaucoup de choses sur les autres dangers identifiés.

ENRICHISSEMENT EN MATIÈRES NUTRITIVES

Conséquence : Accroissement de la fréquence, de la distribution et de la nature des proliférations d'algues qui nuisent à des organismes sauvages et d'élevage, y compris leur toxicité potentielle pour l'homme et/ou des organismes sauvages et d'élevage, ainsi que leurs effets sur des activités humaines et l'utilisation de l'eau douce comme matière première.

Besoins en matière de recherche : Étant donné que l'échelle des modifications de l'environnement résultant de l'élevage de poissons en cages en eau douce peut aller du niveau local à l'ensemble du bassin, la gravité des modifications peut aller de faible à modérée, alors que la probabilité qu'elles se produisent est probablement modérée. Toutefois, les connaissances sont insuffisantes quant au devenir à long terme des matières nutritives, en particulier le phosphore présent dans les particules de déchets. La priorité de recherche est généralement modérée en raison du niveau élevé d'incertitude quant à la gravité des modifications et à leur survenance. La priorité de recherche sur le devenir des matières nutritives présentes dans les particules de déchets est également modérée.

Besoins en matière de surveillance : Étant donné le peu de données récentes disponibles, la surveillance de la production primaire, de la composition de la communauté algale ou des changements dans la biomasse à proximité de toute grande installation d'aquaculture en eau douce permettrait d'obtenir de l'information utile.

POLLUTION CHIMIQUE

Conséquence : Les rejets, accidentels ou approuvés, de produits chimiques dans les eaux des sites aquacoles aboutissent à des niveaux de ces produits dans l'environnement qui sont toxiques pour la faune et la flore indigènes.

Besoins en matière de recherche : Il est interdit, en vertu de l'article 36 de la *Loi sur les pêches*, de rejeter une substance nocive dans des eaux où vivent des poissons. Bien que la gravité potentielle d'un tel rejet soit élevée, en particulier dans les lacs de petite taille, la probabilité qu'il se produise est extrêmement faible ou négligeable. Le besoin en matière de recherche visant en particulier les apports imputables à l'aquaculture est faible. Toutefois, comme il l'est indiqué dans l'introduction de la présente section, peu d'information est disponible sur l'aquaculture en eau douce en général, de sorte qu'il existe une priorité de recherche pour au moins établir l'ampleur du problème.

MODIFICATION ET PERTE D'HABITAT

Conséquence : Enrichissement, en sédiments fins et en matières organiques, des sédiments du fond près des cages entraînant des changements dans la structure et la fonction de la communauté benthique.

Besoins en matière de recherche : En raison de la nature localisée de l'enrichissement, la gravité de la modification potentielle de l'habitat est classée comme faible, bien que la probabilité que l'enrichissement se manifeste soit élevée. Les modèles de prévision pour les eaux douces doivent être validés de sorte à ce que leur efficacité pour le choix des sites et la gestion puisse être confirmée. La priorité de recherche est modérée.

Conséquence : Réduction de la teneur en oxygène dissous jusqu'à des niveaux stressants ou létaux pour les poissons.

Besoins en matière de recherche : Il existe une grande part d'incertitude à savoir si les fermes piscicoles contribuent ou non dans une grande mesure à l'épuisement d'oxygène dans les lacs d'élevage. La gravité de l'effet est élevée mais il existe une incertitude quant à la vraisemblance qu'il se produise. Les besoins en matière de recherche sont donc modérés.

Conséquence : Changement des courants et modification de l'habitat physique ayant des effets sur les organismes résidants.

Besoins en matière de recherche : Étant donné que les changements potentiels sont hautement localisés, leur gravité est considérée comme faible. La probabilité qu'ils se manifestent est modérée. Les besoins en matière de recherche sont essentiellement les mêmes que ceux concernant la compréhension des effets de la modification de l'habitat du poisson et l'identification des mesures de compensation appropriées. La priorité de recherche est faible.

CHANGEMENTS DANS LES POPULATIONS DE POISSONS SAUVAGES

Conséquence : Changement dans l'abondance des ressources trophiques endémiques au niveau de populations.

Besoins en matière de recherche : La gravité de l'effet est faible ou négligeable, et la probabilité qu'il se produise est faible dans les situations où la charge en déchets est faible par rapport à la taille de l'écosystème et le temps de séjour dans celui-ci. Les

besoins en matière de recherche sont donc classés comme faibles. Toutefois, étant donné le manque d'information pour l'élevage de poissons en eau douce au Canada, des recherches sont requises pour obtenir des données de base.

Conséquence : Baisse appréciable de la survie des poissons indigènes résultant de changements génétiques entraînés par l'accouplement avec des organismes de culture ou du déplacement attribuable à la compétition.

Besoins en matière de recherche : La gravité de l'effet potentiel est faible étant donné que la seule espèce touchée est l'espèce introduite. Les opinions concernant la probabilité qu'il se produise varient énormément; elles la situent de faible à élevée. Il existe également une grande part d'incertitude concernant la gravité et la survenance de cet effet. Bien que la priorité de recherche soit modérée à élevée, le défi sera d'identifier les activités de recherche qui permettront de nettement réduire l'incertitude qui entoure la gravité des changements potentiels et la probabilité que les effets se produisent.

Besoins en matière de surveillance : La surveillance du nombre et de la présence d'évadés, ainsi que de leur progéniture, dans le milieu sauvage donnera une idée de l'ampleur potentielle du problème.

INTRODUCTION D'AGENT PATHOGÈNES

Les points ci-dessus concernant la transmission d'agents pathogènes à des poissons marins s'appliquent dans la pleine mesure à l'élevage de poissons en eau douce.

RECHERCHE EN APPUI DES ASPECTS RÉGLEMENTAIRES

Le présent cadre se veut un moyen objectif pour identifier les priorités de recherche au niveau des programmes.[8] À mesure que l'industrie évolue ou que de nouvelles données sont publiées, le cadre peut être facilement appliqué pour réévaluer les priorités. Les projets présentés pour approbation au titre de ces priorités de recherche devraient faire l'objet d'une analyse coûts-avantages afin de peaufiner davantage les priorités.

Des progrès réels au titre de ces besoins en matière de recherche ne peuvent être réalisés que dans un contexte de recherche stable. En raison du niveau élevé de variabilité des systèmes naturels, la plus grande partie des recherches nécessiteront la tenue de deux à trois années d'observations sur le terrain, suivie de l'analyse et de l'interprétation des données. Dans d'autres domaines, d'importants progrès ne peuvent être faits que par le biais de programmes de surveillance à long terme, qui requièrent la conclusion d'ententes de coopération avec d'autres ordres de gouvernement, l'industrie et peut-être d'autres intervenants.

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[8] « Niveau de programme » est synonyme de « niveau de danger », c'est-à-dire est-ce que des recherches doivent être menées dans le but de réduire l'incertitude ou d'identifier des mesures d'atténuation pour un danger particulier? Les dangers sont les activités ou les conséquences d'une activité qui peuvent perturber la structure ou la fonction d'un écosystème.

INTRODUCTION

BACKGROUND

The Canadian Council of Fisheries and Aquaculture Ministers (CCFAM) has directed their Aquaculture Task Group (ATG) to develop an Aquaculture Framework Agreement (AFA). The AFA will provide the basis for bilateral negotiations between federal, provincial, and territorial governments to develop memoranda of understanding for aquaculture in a consistent manner. Part of the process of developing the AFA is identifying the scientific research needs to support the Agreement.

This discussion paper has been prepared to provide advice on how to identify scientific research needs to support the regulatory needs of the AFA. An initial application of the proposed methodology is also presented. However the AFA is in a development phase. Consequently this paper will address the subject strategically and focus on the process to determine science research needs related to environmental interactions with aquaculture. There will undoubtedly be some overlap with another initiative to identify research needs for the Research, Development, and Commercialization (RDC) component of the AFA. However it is better to have some overlap rather than omit important components of these research needs.

The success of scientific research in providing support for a sustainable aquaculture industry is highly dependent upon the vision of the ATG and the cooperation of its members and the industry. Given the limited research capacity in Canada, the importance of careful selection of research initiatives and stability of the funding mechanism cannot be overstated. The risk-based approach presented here can provide the basis for informed decision making with respect to soliciting and funding research activities.

Over the past few years there have been a number of extensive reviews of the research literature on environmental interactions with finfish culture, particularly salmon culture. Of particular note is the work of the United Nations Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection Working Group on Environmental Impacts of Coastal Aquaculture (GESAMP WG 31), the International Council for the Exploration of the Sea Working Group on Environmental Interactions with Mariculture (ICES WGEIM), and DFO research and advisory activities including the inter-regional project Environmental Studies for Sustainable Aquaculture, the extensive review of current knowledge in a series of peer-reviewed papers by DFO scientists, and the National Advisory Process meetings that produced the Science Advisory Reports 2005/0034 for finfish aquaculture and 2006/005 for bivalve aquaculture. This paper relies almost entirely upon those critical reviews for the state of knowledge regarding identified risks.

Currently, salmon net-pen aquaculture in coastal areas is the dominant aquaculture activity in Canada as well as the most controversial and most studied, therefore that is the natural focus of this paper. By extension and reference, research

needs in support of regulation for freshwater finfish and marine shellfish aquaculture activities will also be addressed.

LIMITATIONS

This is a discussion paper and therefore is intended not as a final product but rather as a basis for dialogue within DFO and the ATG. This current version does not contain any reference to issues that are the responsibility of Environment Canada – specifically, several reviewers have mentioned interactions with birds – but there may be other issues as well.

Absent from this paper is any discussion of the unintentional introduction of invasive species as a result of the transfer of cultured animals. This is deemed to be a regulatory control issue that does not require "aquaculture-specific" research. Transfers are controlled under DFO's introduction and transfer regulations and research is being conducted on various aspects of aquatic invasive species under special funding.

Sea lice are not dealt with specifically, however they are implicitly covered in the section on Marine Finfish Culture, below, under "Aquatic animal diseases of provincial/territorial concern," and "Local aquatic animal disease."

In the section on Freshwater Finfish Culture, below, there is only limited reference to effluents from land-based facilities. It is felt that although the input vector is somewhat different than that for cage culture, the hazards are very similar and therefore separate analysis was not warranted. However the issue of pond culture has not been addressed at all in this document. The subject is covered by Walker et al. 2003, and there may be adequate material there to apply the framework described herein.

SCIENCE SUPPORT FOR REGULATION OF AQUACULTURE

The research needs of an industry are dictated by its need to meet regulatory requirements and its need to be economically sustainable. Regulatory requirements can be defined narrowly as the legislation governing the industry. However from a practical perspective there is a broader requirement to meet the general public's expectations regarding self-regulation and environmental stewardship. For a developing industry that is competing for space already utilized by a wide range of human activities, this latter driver can be as significant as the legal drivers. Therefore the scope of this paper encompasses the research needs engendered by regulation in the broadest sense.

It is important to make the distinction between research needs and knowledge gaps. In all cases where a research need is identified there is a knowledge gap to be addressed. However, the converse is not always true; i.e. where there is a knowledge gap there is a priority for research. If the knowledge gap does not significantly affect our ability to assess the potential severity and probability of occurrence of a hazard, then in the context of this analysis it is not a regulatory research priority.

This approach is consistent with numerous DFO and provincial initiatives underway to develop integrated management plans for coastal areas. In the future this is

likely to be the context for the management of all marine coastal aquaculture activities. In this context, the aquaculture industry is one of many human activities that affect and are affected by the environment in the coastal zone. To meet an increasing demand for this type of advice, the DFO Science Sector has adopted a strategic framework for delivering scientific advice. Titled "Ecosystem Science Framework in Support of Ecosystem-based Management,"[9] it also promotes identifying and conducting research in the broad context of integrated management. Science advice is developed and provided on a spatial rather than activity basis, meaning that the aquaculture industry will be treated as another acceptable human activity in the coastal zone that must be managed to meet the overall ecosystem objectives for the management area.

Assessing the science needs for the regulatory aspects of the AFA from a broad integrated management perspective is also consistent with the Government of Canada's intent as expressed by the Oceans Act and its implementation through the Oceans Action Plan.

THE APPROACH

In considering a framework for identifying research needs in support of aquaculture regulation it was decided that a risk-based approach was essential. Research needs will be identified based on the potential risk associated with identified hazards of aquaculture activities.[10] The science of risk analysis is well advanced and no attempt will be made to provide a primer on risk analysis in this document. However there are a couple of important elements to remember. First, the risk analysis as applied here is an objective analysis based on scientific information about the nature of the effects, knowledge gaps, and the probability of occurrence. It is recognized that socioeconomic, ideological, and political elements are relevant to comprehensive risk analysis. However this paper deals only with the applied science aspects recognizing that regulatory decision-making is influenced by these other factors. Second, in the overall context of the development of the AFA, it is critical to remember that communication is an integral part of any risk assessment and explanations of regulatory decisions made within socioeconomic and political contexts.

To provide a consistent treatment of all risks, a tabular summary of a risk analysis for each potential effect is provided. Broadly accepted characterizations for severity of impact[11] and probability of occurrence are used along with a decision table that indicates whether or not the risk associated with a particular impact is "acceptable" (see Annex 1). Risk evaluations that fall in the four corners of the decision table are generally accepted while there is more uncertainty associated with evaluations that fall along the line separating the "accept" and "reject" cells of the table. Risk tolerance, overall integrated management objectives of stakeholders, and legal mandates may modify the acceptance

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[9] A New Ecosystem Science Framework in Support of Ecosystem-based Management, a discussion paper prepared for NSDC, December 2005.

[10] This procedure is described in detail on p. 30 of Hambrey and Southall, 2002.

[11] The definitions of severity concern the impact on the ecosystem. Effects on the industry would be considered socioeconomic.

or rejection of those risks. This decision table is not linked to any regulatory decision-making. For example, DFO Habitat Management might wish to consider developing their own decision table based on the fairly widely accepted definitions of severity and probability of occurrence. Furthermore, the purpose of the decision table is to assign priority to research needs; this should not be confused with determining whether or not there is a violation of any regulation.

Research needs are identified at the program level, not the project level. The highest priority research needs are associated with the highest potential risks that are unacceptable and for which effective mitigation does not exist. There must also be reasonable probability that research can either identify effective mitigation or significantly reduce uncertainty so that the risk analysis can usefully contribute to decision-making. This component of the priority setting process occurs at the project level when research project proposals are being evaluated.

The meaning of the priority for research needs to be clearly understood. Because research related to a particular end point is determined to be low it does not mean that no further research is required or warranted. It means that the research that is conducted in this area must more clearly advance management or regulatory decision-making. Likewise, because a research need is determined to be high priority it does not mean that all research in this area should be funded, but it does mean that we should be less risk adverse in funding research in this area.

Monitoring needs have also been identified. Monitoring is an essential part of environmental research. Unfortunately, for 20 years there has been intense aquaculture industry activity in Canada without a coherent and useful monitoring program. Changes in ecosystem function and structure are seldom dramatic events; rather, they occur over long periods of time with subtle effects that may precede more significant changes. There is no substitute for time series observations of critical ecosystem indicators. Detection of temporal trends is a desirable management indicator particularly in the absence of well-defined targets.

The concept of indicators, reference points, and targets is fundamental to integrated management plans. These indicators and the associated reference points and targets are often based on scientific knowledge of the area and activities being managed. This knowledge is gained through research on ecosystem structure and function, and environmental interactions with human activities. Identifying these indicators is part of the development of an integrated management plan, a process to which science contributes. Indicators for integrated management are not generally industry specific and therefore development of indicators is not explicitly identified in this document as a research need. The information contained in this report can however be used by stakeholders and scientists to identify broad monitoring needs for the selected end points.

IDENTIFICATION OF INFORMATION GAPS AND ASSOCIATED RESEARCH NEEDS AND MONITORING

The first step in a risk analysis is to identify the hazards. Hazards can generally be classified as real, potential, or hypothetical. While the industry will ultimately have to deal with all hazards, this scientific assessment deals only with real and potential hazards. The hazards associated with the environmental interactions with aquaculture industry activities can be summarized into the following major categories:[12]

- nutrient enrichment: the release of uneaten food, feces, pseudo-feces and dissolved metabolites to sediment and water column.

- chemical pollution: related primarily to the release of therapeutic chemicals used in the treatment of disease and parasitic infections; also includes inorganic contaminants from feed, etc.

- habitat change and loss: changes in seabed, lake or river bottom habitat due to the accumulation of organic matter; also includes the loss of habitat due to conversion of coastal land and wetland.

- changes in wild fish and shellfish populations: the escape and interbreeding of farmed and wild fish and the competition of escaped farm fish for prey and habitat.

- introduction of pathogens: introduction of exotic infectious species (viruses, bacteria, fungi, and parasites); increased abundance of pathogens in the water derived from farmed stock.

- secondary effects on other production systems: social, economic, and environmental effects associated with increased demand for inputs such as forage fish and fishmeal.

  The last of these, while important, is outside of the scope of this discussion paper.

Each of these categories of hazards is broken down further for sea cage culture, marine bivalve culture, and freshwater finfish culture analysis.

FRAMEWORK FOR IDENTIFICATION OF SCIENCE NEEDS

The fundamental assumption for this analysis is that from a scientific perspective scientific research resources are best directed at those hazards that pose the greatest risk to the environment. The framework used here is based heavily upon the approach taken by ICES (2005), which was founded partly in the work of GESAMP WG 31 (Hambrey and Southall, 2002). That approach has been modified slightly for the present application.

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[12] This list is taken from Hambrey and Southall (2002) except for the separation of disease and parasites as a distinct category. This list is also similar to that provided in WGEIM (2005).

After the hazards are identified, the next step in the analysis is the identification of the end points of concern. This is not necessarily the immediate effect associated with a hazard but rather the result that is of greatest concern. For example, consider the transfer of sea lice from caged salmon to wild salmon. The transfer itself is not the result or end point of concern. The concern is that this transfer will result in reduced fitness of wild salmon and subsequent loss in their productivity. A clear statement of the end point is critical.

The next step is a brief statement of the present state of knowledge. This statement is not comprehensive, but instead focuses on the undesirable end point. Information for this section is based largely on the recent science reviews listed under "Sources of Information."

This is followed by a brief statement of how this end point could be viewed in the context of integrated management. Other human activities that might contribute to this impact are also identified and the aquaculture industry activity is placed in that context.

The following table then organizes the information that is relevant to the analysis.

DRIVERS	What specific activity is associated with the identified end point?
	Are there other factors that contribute to the change?
SOURCES	What are the sources of the driver; other industries, etc.
MODIFIERS	Are there natural factors that might modify the effect?
TEMPORAL EXPRESSION	Is there a temporal component to either the activity or the effect?
GEOGRAPHICAL EXTENT	What is the spatial scale of the effect? (also see last par. of this section)
OUTCOMES	How is the effect likely to be expressed?

Finally a qualitative risk analysis is performed using the above information. Based on the definitions provided in Annex 1, a brief statement indicates the potential severity of the end point and the probability of that event occurring. If the associated risk is considered unacceptable, then research and monitoring needs at a program level are identified. It is important to note that only the scientific information is considered here. The acceptability of a risk can be legitimately modified by legal considerations or a socioeconomic risk analysis.

With the exception of the last step, the identification of research and monitoring needs, there is nothing new presented here. Material has simply been taken from the sources noted and placed in this framework. If there are errors in the information or as more recent data become available, the information in the framework can be updated and the analysis can be redone.

Scale is an important factor for many of the risks. Often, the severity of an effect is assessed as low since the effect is highly localized. However in some instances the

scale of industry development is such that the industry occupies a large portion of a particular type of habitat in an area. In such a case the effect ceases to be "local" and the severity would change from low to moderate and the state of knowledge on cumulative impact needs to be considered.

The results of the analyses from the following sections are summarized in Annex 2. Care needs to be exercised in the use of this annex since there are numerous critical details in the text of the following sections that are important to the use of the summarized information.

MARINE FINFISH CULTURE (SALMON)

In Canada, the sea cage culture of Atlantic salmon is the dominant finfish culture activity. Globally, research is continuing on the development of new species such as halibut, cod, haddock, and sable fish for commercial culture. As these developments are moved to commercialization, it is important that the hazards associated with their culture are identified so that appropriate research is undertaken to identify management practices to mitigate any unacceptable risks. At present the culture techniques being used for many of these species are similar to those used for salmon so the environmental interactions are likely to be similar.

Nutrient Enrichment

Macroalgae

End point: Enhancement of macrophyte production affecting other human activities

Previous experience: There are limited studies of the occurrence of this phenomenon, although bio-fouling of cage structures is a well-known management problem. However, where fish farm production is located in waters close to shore it appears there is potential for increased macrophyte abundance. Documented in the Baltic archipelagos, and the Canadian Maritimes, macroalgae do appear to respond to the presence of fish farming with increased abundance. The geographic extent is generally limited to the immediate area of the culture facility and is expected to not significantly last beyond the duration of the aquaculture activity. There is some evidence that far-field effects exist or may occur over time or with increased activity.

Integrated management context: This end point is not unique to aquaculture effects and needs to be considered in the general context of the effects of nutrient enrichment in coastal waters.

DRIVERS	Significantly increased abundance of limiting nutrients
	Substrate in the euphotic zone within the nutrient plume.
	Seed source for macrophytes
	Eutrophication
SOURCES	Aquaculture
	Other nutrient sources, e.g.: - Urban domestic and industrial - Agricultural
MODIFIERS	Dilution regimes
	Depth of euphotic zone
	Other factors limiting primary production
TEMPORAL EXPRESSION	Unclear, but likely to be seasonal and unlikely to be expressed outside of growing season once nutrient source removed. Timeframe for organic enrichment from decaying macrophytes longer but still limited.
GEOGRAPHICAL EXTENT	Dependent on dispersion and advection of nutrients and distribution of substrate
OUTCOMES	Increased habitat heterogeneity that is usually associated with increases in local secondary productivity
	Fouling of nets and cage infrastructure can impede water flow in cages and contribute to oxygen depression in cages through dark respiration.
	Increased macroalgae resulting in increased habitat for sheltering prey species
	Increased macroalgae can impede vessel traffic
	Increased macroalgae may affect aesthetic values for residents and tourism.

Research needs: Identification of far-field effects is hampered by the lack of baseline data and high natural variability. Potential effects can be mitigated through site selection, e.g., limits on total production in basins where nutrients may accumulate. Research priority is low since severity is low and the probability of occurrence is moderate to low. Mitigation is available.

Monitoring needs: Pre-development data and annual surveys of peak macroalgal production. Trend over time data is an invaluable scientific research and adaptive management resource.

Microalgae

End point: Increase in frequency, distribution, and nature of algal blooms affecting human activities or resulting in toxicity to humans and/or wild and cultured organisms

Previous experience: It is not clear whether significant changes in microalgal abundance occur in association with fish culture. Though considered possible because of documented increases in nutrient concentrations, it has not been linked to salmon farming

in Europe, North America or Chile. Conditions that are necessary and sufficient to trigger harmful algal blooms are unknown.

Integrated management context: There can be many sources of inorganic nutrients in the coastal zone. Therefore, inputs from aquaculture must be managed in the context of an overall water quality objective. Total nutrient loading may have to be apportioned among various human activities.

DRIVERS	Inorganic nutrient loading
	Temperature, light
	Seed sources
SOURCES	Shellfish culture activities
	Fish farms
	Other nutrient sources, e.g.,
	– Urban sewage and run-off
	– Tidal exchange
	– Agricultural run-off
MODIFIERS	Residence times/dilution regimes
	Transport regime
TEMPORAL EXPRESSION	Likely only to occur during growing season. Once source of nutrients is removed it is unlikely to persist.
GEOGRAPHICAL EXTENT	Dependent on current derived dilution regimes and distribution of nutrients.
OUTCOMES	Potential for significant increases in algal abundance and for the occurrence of harmful algal species affecting other resource users.
	Occurrence of blooms of various species has a direct negative effect on farmed and wild fish, i.e. stress and mortality
	Die-off of large blooms creates depressed oxygen conditions resulting in stress and mortality of farmed fish.

Research needs: Effective experimental design to study this potential effect is confounded by high natural variability coupled with a lack of definitive knowledge of the conditions that are necessary and sufficient to generate nuisance blooms. Nutrient loading has been mitigated by changes in food formulation and better food conversion ratios, however metabolic nutrient excretion cannot be effectively reduced. The severity of the effect would be rated as low to negligible and the probability of occurrence as low to extremely low; therefore the research priority is low.[13]

Monitoring needs: Monitoring of coastal plankton populations at local and regional scales can provide information that is useful for site selection and for site management to reduce potential effects on the industry from harmful algal blooms. Trend over time data is an invaluable scientific research and adaptive management resource.

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[13] From an industry development perspective the research priority is likely higher due to the economic impact that harmful algal blooms, which are not necessarily connected with nutrient enrichment through aquaculture, have on the industry.

Chemical Pollution

Toxic chemical levels in the environment that effect native flora and fauna

End point: Releases, accidental and approved, of chemicals on aquaculture sites result in environmental levels that are toxic to native flora and fauna.

Previous experiences: A number and variety of chemicals are used on aquaculture sites. There has not been a great deal of research on the fate and effect of these chemicals. Limited studies in New Brunswick and British Columbia indicate enhanced levels of copper and zinc near cage sites. The enhanced occurrence of antibiotic resistant bacteria in sediments near cage sites has also been documented. There have been numerous laboratory studies on the effects of chemicals used to control sea lice however little fieldwork has been conducted. Waste and unassimilated fish feed appears to one of the pathways by which the industry introduces contaminants into the environment.

Integrated management context: Aquaculture is one of many human activities that accidentally or intentionally result in the release of contaminants into coastal waters. In some areas long-range atmospheric transport can be a significant vector. It is a violation of the Fisheries Act to discharge a deleterious substance into Canadian waters however non-point discharges are difficult to detect and monitor. Aquaculture industry inputs need to be managed in the context of overall water quality objectives.

DRIVERS	Accidental and approved discharges of chemicals into the environment
	Chemical discharges from aquaculture sites
	Other local and long-distance inputs
SOURCES	Fish food
	Chemical therapeutants to control and treat disease
	Sea lice control chemicals
	Anti-foulants to control growth on cage structures
	Domestic and industrial sewage and storm discharges
	Local and long distance industrial discharges
MODIFIERS	Advection and dispersal of contaminants
	Concentration in organically rich sediments
TEMPORAL EXPRESSION	Concern is regarding levels of persistent organic pollutants that are not biodegradable and accumulate over time. Effects are expected to be due to chronic exposure and expressed as sub-lethal effects. Short-term acute toxicity is rare.
GEOGRAPHICAL EXTENT	Primary concern is the immediate vicinity of the site but local factors could influence focus of potential effect
OUTCOMES	Potential short-term acute toxicity on non-target organisms
	Potential sub-lethal chronic effects on marine organisms and populations

Research needs: In general, only rarely has there been a demonstration of sub-lethal chronic effects at the population level of contaminants in the marine environment. Therefore severity of this potential effect would be rated as low since the effects are likely to be expressed only at a local level. The probability of occurrence is at most low and possibly extremely low. The priority for research is rated low, however a mass balance model of area-wide inputs of chemicals of concern would clarify the analysis of the risk for specific locations.

Monitoring needs: Temporal trend data for a select group of priority pollutants in one or more environmental compartments would provide useful information for industry and integrated management decisions. Trend over time data is an invaluable scientific research and adaptive management resource.

Habitat Change and Loss

Enrichment of bottom sediments with fine sediments and organic matter

End point: Enrichment of bottom sediments near cages with fine sediment and organic matter resulting in changes in benthic community structure.

Previous experiences: This undesirable end point is well documented in areas that are depositional, i.e. where there is limited advection and dispersion of fine particulate material. Typically this is not a problem at erosional or deep-water sites where the material is well dispersed before reaching the bottom. However only limited research has been conducted in deep-water or in boulder-rocky substrates. Changes in benthic community structure are obvious under impacted sites and there is evidence in areas of extensive aquaculture development that there are cumulative, far-field effects. Some sites vary from being depositional to erosional on a seasonal basis and little is known about long-term effects on these sites. Predictive models have been developed and are being used for site selection.

Integrated management context: There are other anthropogenic and natural sources of both fine sediments and organic matter. Natural sources include river run-off and decaying macrophytes. There are numerous anthropogenic sources that can be managed; however, there are also numerous natural sources that cannot be managed.

DRIVERS	Particulate organic matter from culture operations
SOURCES	Uneaten and waste feed
	Excretion of particulate material
	Agricultural run-off
	Domestic and industrial wastes
MODIFIERS	Advective and dispersive forces at site
	Dissolved organic matter
	Natural benthic substrate
	Density of aquaculture operations

TEMPORAL EXPRESSION	Amount and rate of accumulation is a function of site characteristics and management.
	Seasonal wind patterns can change the duration of effects.
	Site fallowing effects a return to pre-development conditions but time required is dependent on site characteristics and the extent of change.
GEOGRAPHICAL EXTENT	Build-ups resulting in benthic community change are usually limited to the vicinity of the cages. High natural variability confounds the ability to demonstrate far-field effects.
OUTCOMES	Undesirable changes in benthic community structure in vicinity of cages.
	In extreme cases release of ammonia and/or methane from anoxic sediments effecting overlying water quality.

Research needs: The changes will be localized therefore the severity of the effect is low. However the probability of occurrence is high. Mitigation is available through informed site selection coupled with good management practices. This includes consideration of essential habitat for any species at risk; even a localized change to such habitat could be considered unacceptable. In general the research priority would be rated medium. Validation of deposition models is required to insure that advice on site selection is reliable. Research is also needed to understand the density factor; how many farms in a basin are too many?

Monitoring needs: Monitoring of benthic conditions under cages coupled with data on such site operations as feed conversion rates, growth rates, mortalities, disease, parasites, etc., would provide the basis for much-needed science advice on site selection and best management practices. Trend over time data is an invaluable scientific research and adaptive management resource.

Reduction of water column oxygen to levels that are stressful to wild and cultured fish

End point: Reduction of water-dissolved oxygen concentration to levels that are stressful or lethal to fish

Previous experiences: Fish kills have occurred at fish culture sites due to low oxygen concentrations, usually in conjunction with the die-off of a large phytoplankton bloom. Sites have also encountered low oxygen levels at periods of maximum growth rate and biomass for the cultured fish, which often coincide with highest water temperatures and thereby lowest oxygen solubility. The situation can be further exacerbated by heavy fouling of cages, which reduces water renewal in the cages and increases consumption of oxygen in the dark. A large portion of the oxygen demand at the cage sites is fish respiration. The oxygen depression resulting from the culture operations is isolated to the immediate vicinity of the cages.

Integrated management context: There are often numerous sources of biological and chemical oxygen demand (BOD and COD) in coastal waters that can amplify the demand from the aquaculture activity itself. Careful site selection and continued management of

all BOD and COD sources in the management area can insure sustainability of aquaculture activities.

DRIVERS	Biological and chemical oxygen demand from natural and anthropogenic sources.
	Relatively large-scale aquaculture operations.
SOURCES	Fish respiration and decay of farm organic wastes
	Dark respiration of phytoplankton and macroalgae
	Industrial and domestic sewage
MODIFIERS	Temperature
	Flushing
	Fish density, total biomass, and feeding rate
TEMPORAL EXPRESSION	Short-lived occurrence in marginal sites with high production. Condition returns to normal immediately upon removal of excessive BOD.
GEOGRAPHICAL EXTENT	Localized to fish cages.
OUTCOMES	Fish morality in extreme cases
	Fish are stressed resulting in increased susceptibility to disease. Potential effect is increased when coupled with sea lice infestation.

Research needs: From an ecosystem perspective, the severity is extremely low; however from a fish farmer's perspective the effect is severe. Given good site selection and the use of best business practices the potential occurrence is extremely low. The cause and effects relationships are well known and the occurrence of these events is predictable. Research priority is low.

Monitoring needs: Dissolved oxygen is a potential indicator for effects at erosional sites where any changes are more likely to be expressed in water column components of the ecosystem than in benthic components. Trend over time data is an invaluable scientific research and adaptive management resource.

Changes in physical habitat [14]

End point: Changes in the currents and physical habitat affecting resident organisms

Previous experience: Though not well documented in the literature, experience has shown that culture structures can influence current speeds and direction in the immediate vicinity of the structures. Areas of reduced currents are generally experienced within structures and in the lee of culture facilities. At shallow sites, the area under large culture facilities may experience increased current speeds, and this may consequently alter the local pattern of accumulation of fine particulate material. These changes last only as long as the culture facilities are in place and influence only a small area in the vicinity of the

[14] Portions of the text for this section have been extracted from Annex 3 of the 2005 report of the ICES WGEIM. However this report has not been reviewed by ICES and cannot be considered as ICES advice on this issue. It has been reviewed by the members of the WGEIM.

culture facility. As the area affected is small, it is anticipated that individuals or species occupying it may be impacted, but it is unlikely that whole ecosystems or species will experience significant effects. This of course is based on the assumption that environmentally or biologically significant areas – particularly those for species at risk – are avoided during the site selection process. It is also based on the assumption that sites have been located to avoid situations where water flow would likely be affected.

DRIVERS	Size and number of culture systems
	Increased habitat heterogeneity
	Increase in areas for plant and animal settlement
	Changes in current velocities
SOURCES	Shellfish culture activities
	Fish farms
	Natural erosional and depositional events
	Storms
	Other man-made structures, e.g. artificial reefs, harbor construction
MODIFIERS	Structural design
	Orientation of structures
	Macrophyte distribution
	Placement of structures relative to currents
TEMPORAL EXPRESSION	Limited to the duration of the structures
GEOGRAPHICAL EXTENT	Proximate to the structures
OUTCOMES	Changes in the dilution and erosional regimes effecting water quality and sedimentation processes.

Research needs: The severity of effect of the alteration of physical habitat from aquaculture activities is deemed to be low or negligible because of the limited geographical extent and its temporary nature. There is a potential for more serious changes but these can be readily mitigated through proper site selection. The probability of occurrence is high in the absence of informed site selection, but low with proper site selection practices. The overall assessment is that this is an acceptable risk. No priority research is identified.

Monitoring needs: No requirements.

Changes in Wild Fish Populations

There is considerable scientific uncertainty, and therefore debate, about the various potential effects of escapees of cultured fish on wild fish populations. A recent review of the state of knowledge on these issues was completed at a joint ICES/NASCO symposium held in November 2005. When the report from that symposium is available later in 2006 the research needs identified here should be reviewed. The following analysis is based on the report from the 1997 ICES/NASCO symposium.

Changes in fitness of wild populations due to genetic intergradation [15]

End point: Significant decline in survival of wild salmon due to genetic changes resulting from interbreeding with cultured organisms.

Previous experience: While this obviously applies to the interaction of escaped Atlantic salmon with wild stocks on the east coast it can also apply generally to the case where farmed species are a native species, e.g. Coho and Chinook salmon on the West coast. No evidence has been found that commercially cultured aquatic organisms have novel alleles otherwise absent from feral populations of the same species. Differences in allelic frequencies have been noted. Interbreeding has been documented between escaped and feral Atlantic salmon. Interbreeding is more likely to occur in areas close to the location of the escape. The effect of intergradation is likely to be proportional to the relative number of wild and cultured organism interbreeding. Where only a few individuals are involved, the effects are likely to be less. Where relatively large-scale genetic intergradation has occurred, there has been reduced fitness and survival of the feral population. Where studied, hybrids of single interbreeding events rapidly disappear from the feral population and the effect is likely to be reversible through natural selection over a period of a few years. Where large-scale repeated escapes occur the effects are likely to be larger and the consequences unpredictable. Metapopulation dynamics are likely to buffer the effects of occasional intergradation events, but they do not buffer effects from repeated large-scale events.

Integrated management context: The effects of escapees need to be considered in the context of stock enhancement activities using hatchery stock in the same area.

DRIVERS	Proportion of wild population interbreeding with organisms escaping culture
	Relative difference between wild and cultured fish genome
SOURCES	Fish farms
	Strays from other endemic populations
	Genetic effects of - Stock improvement - Transfers - Enhancement - Genetic selection associated with fishing activities
MODIFIERS	Metapopulation structure
	Population size (effects of drift and inbreeding)
	The effects of selection by other human activities
TEMPORAL EXPRESSION	Where intergradation occurs it is likely to effect at f1 generation. Effects on f2 and beyond are unclear.
GEOGRAPHICAL EXTENT	Dependent on migratory behavior and breeding distribution but most likely in areas adjacent to escape.

[15] Portions of the text for this section have been extracted from Annex 3 of the 2005 report of the ICES WGEIM. However this report has not been reviewed by ICES and cannot be considered as ICES advice on this issue. It has been reviewed by the members of the WGEIM.

OUTCOMES	Reduced fitness of feral population

Research needs: The severity of the potential effect is moderate to high; where a stock is listed by COSEWIC as an endangered species the effect could be rated as catastrophic. There is however a wide range of scientific opinion on the probability of occurrence ranging from low to high. Continued research activity is a high priority. The challenge will be to identify research activities that can significantly reduce the uncertainty regarding either the severity of the potential effect or the probability of the outcome being expressed.

Monitoring needs: Monitoring the number of escapees and the occurrence of escapees and their progeny in the wild will provide an indication of the potential scale of the problem.

Changes in trophic resources[16]

End point: Changes in the abundance of endemic trophic resources at the population level

Previous experience: There is a limited amount of information on the consumption of wild prey by cultured fish. Salmonids cultured in marine cages have been shown to consume endemic invertebrate thigmotatic or fouling organisms. To a much lesser degree, they have been seen to consume juvenile (post-larval) fish. No evidence has been presented to evaluate the effect of consumption of the invertebrates, although they are unlikely to represent a significant food resource to the cultured fish. Analysis of the level of consumption of juvenile wild fish suggests that it is unlikely that predation by caged fish would measurably affect the survival of the wild fish.

DRIVERS	Number and biomass of cultured organisms
SOURCES	Fish farms
	Natural recruitment phenomenon
	Changes in climatic and oceanic regimes (carrying capacity)
	Effects of other human activities – Enhancement activities (e.g., artificial reefs) – Fishing
	Organisms that have been introduced or spread from other areas.
MODIFIERS	Degree to which tropic requirements may be supplemented by feed supplied by aquaculture.
	Degree to which culture facilities restrict culture organism's access to wild trophic resources
	Human harvests
	Oceanic regime changes and natural variation in the abundance of wild organisms.

[16] Portions of the text for this section have been extracted virtually verbatim from Annex 3 of the 2005 report of the ICES WGEIM. However this report has not been reviewed by ICES and cannot be considered as ICES advice on this issue. It has been reviewed by the members of the WGEIM.

TEMPORAL EXPRESSION	Recovery of wild trophic resources (organisms) is dependent on the degree to which production (as opposed to standing stock) of wild organisms is effected.
	If production of trophic resources is unaffected, recovery is expected to immediately follow cessation of culture activities.
	If production has been affected, the return to historical levels will depend on recruitment and growth of natural populations. If the affected organisms are low in the food web, the recovery period is expected to be short, in the order of a year or two.
GEOGRAPHICAL EXTENT	Dependent on the distribution and intensity of culture activities in relation to the geographic distribution of the prey species
OUTCOMES	Depression in local abundance of trophic resources

Research needs: The severity of the effect is low or negligible and the probability of the outcome being expressed is low. Research needs are therefore rated as low. It should be noted that scale is an important factor for this hazard; extensive developments in enclosed areas represent a greater hazard with greater potential severity and probability of occurrence.

Monitoring needs: None identified.

Competition of escaped fish with native species

End point: Escaped cultured fish compete with native fish for essential habitat resulting in reduced fitness or competitive displacement of the native species.

Previous experience: There is no comprehensive review of this issue available; what follows is based on selective reading of a number of papers and may not reflect the present state of informed scientific opinion.

There is a body of research on the interactions between escaped farm and native fish of the same species. Farm fish manage to survive and reproduce, but they are generally less productive than their wild counterparts. However when the ratio of farm to wild fish becomes large, reduced fitness or competitive displacement of the wild fish is more likely to occur. There is little information on the interactions between different species and the situation is likely to be extremely complex. There are certainly many well-documented cases of the accidental or intentional introduction of an exotic species causing major changes at the ecosystem level.

Integrated management context: In the case of interaction between farm and native fish of the same species, the effects of escaped farm fish must be considered in the context of any stocking or enhancement activities for that species.

DRIVERS	Escaped cultured organisms
SOURCES	Fish farms
	Organisms that have been introduced or spread from other areas.

MODIFIERS	Security of farm sites
	Availability of appropriate wild prey and/or habitat
	Contribution of stock enhancement to "native" populations
TEMPORAL EXPRESSION	Recovery of wild trophic resources (organisms) is dependent on the degree to which production (as opposed to standing stock) of wild organisms is effected.
	If production of trophic resources is unaffected, recovery is expected to immediately follow cessation of culture activities.
	If production has been effected, the return to historical levels will depend on recruitment and growth of natural populations. If the effected organisms are low in the food web, the recovery period is expected to be short, in the order of a year or two.
GEOGRAPHICAL EXTENT	Dependent on the distribution and intensity of culture activities in relation to the geographic distribution of native species
OUTCOMES	Depression in local abundance of native species

Research needs: There is considerable uncertainty regarding both the severity of this hazard and its potential for occurrence. Of particular concern would be competition for food or habitat for any species at risk. The potential severity ranges from low to catastrophic and the probability of the outcome being expressed ranges from negligible to high. Research to reduce the uncertainty is a high priority, but success will be confounded by complexity of interactions and high natural variability.

Monitoring needs: Monitoring of the number and location of escapees and monitoring the occurrence of escaped fish at habitat for species at risk could be an effective research and management tool.

Introduction of Pathogens

Federally regulated aquatic animal diseases:

End point: An exotic aquatic animal disease regulated by federal legislation is introduced and/or transferred into a previously disease-free site/zone/naïve population, resulting in significant resource, economic and/or trade-related losses.

Previous experience: There are numerous instances where introduction and transfer of trade-related aquatic animal diseases occur internationally and within national boundaries. More problematic are the "unknowns" of aquatic animal disease (AAD) epidemiology, including pathogen interactions among wild and cultured aquatic animal populations. The results of peer-reviewed scientific papers, anecdotal accounts, and opinions paint a complex picture for pathogen introduction and interactions, such that a precautionary approach (PA) is frequently but inconsistently invoked according to diverse interpretations of the concept. In many cases, the introduction of exotic AADs results in serious export losses with the associated pathogens becoming enzootic, and frequently subject to ongoing costly provincial, territorial, and industry control/management as AADs of provincial/territorial concern.

Integrated management context: This end point relates to all aquatic animal resource sectors and needs to be considered in the context of regulation, prevention, and compliance – specifically with regard to international transport/travel, importation, introductions and transfers.

DRIVERS	International/intranational transport, travel and commerce; natural movements/disease transmission characteristics of aquatic animal populations
	Controlling pathways for introducing exotic aquatic pathogens into naïve populations/zones, including via seafood/live aquatic animal trade
	Aquaculture context (e.g., vulnerable monocultures; egg/brood stock trade)
	Need to protect wild stocks/species, capture fisheries and sport fishing
	Uncertainty concerning aquaculture/wild stock disease interactions
SOURCES	Endemic areas in other countries or regions (provinces/territories/zones) – environment, reservoirs, vectors, carriers
	Economic sabotage
	Domestic or exotic *de novo* emergence of serious AAD pathogens/strains
MODIFIERS	Federal regulation and control – transport, travel, trade
	Stakeholder compliance and participation
	Surveillance, testing and communication that are sound, timely and accurate
TEMPORAL EXPRESSION	Potential to occur anytime
GEOGRAPHICAL EXTENT	Potential to occur anywhere – notwithstanding "known" pathogen distribution, limitations, expression and characteristics
OUTCOMES	Economic/job losses, particularly related to seafood exports
	Limitations/restrictions/effects for all seafood sectors and many communities
	Temporary/permanent effects on species, stocks, biodiversity and ecosystems

Research needs (partnerships implicit): Research priority is high as consequence of severity being high and the probability of occurrence being moderate. Mitigation is limited. Ongoing, targeted development/improvement of diagnostic testing is needed to optimize scope, ease of use, timeliness, integrity, accuracy, specificity, sensitivity, and cost-effectiveness (e.g., rapid tests, microarrays, pathogen characterization, biosecurity safeguards, international reference test design). Ongoing, targeted research of occurrence, epidemiology, pathogenesis and pathology of federally regulated exotic aquatic animal pathogens/diseases is also a priority.

Monitoring/control needs: Statistically valid and internationally accepted exotic disease surveillance/monitoring and sound sampling/testing are required to bolster baseline, exposure and occurrence data.

Aquatic animal diseases of provincial/territorial concern

End point: A severe enzootic aquatic animal disease (AAD), not governed regionally by federal field control measures but of "named" concern to a province/territory, becomes epizootic and/or exceeds regulatory/husbandry tolerances, in/near regional

sites/zones/populations with a potential for significant resource, economic and/or trade-related losses.

Previous experience: There are numerous instances where epizootics of aquatic animal diseases of provincial/territorial concern occur regionally. More problematic are the "unknowns" of AAD epidemiology, including disease interactions among wild and cultured aquatic animal populations. The results of peer-reviewed scientific papers, anecdotal accounts and opinions paint a complex epidemiological picture for these AADs, such that a precautionary approach (PA) is frequently but inconsistently invoked according to diverse interpretations of the concept. In many cases, epizootics of AADs of provincial/territorial concern cause serious resource and/or economic losses in the face of expensive control options that offer no prospect for eradication.

Integrated management context: This end point relates to all aquatic animal resource sectors and needs to be considered in the context of regulation, prevention and compliance – specifically with regard to regional transport, travel, introductions and transfers.

DRIVERS	Intranational/regional transport, travel, commerce, introductions and transfers (i&t); natural movements/disease transmission characteristics of aquatic animal populations
	Controlling pathways and avoiding conditions that expose aquatic animal populations to AADs of provincial/territorial concern (and federally regulated AADs)
	Aquaculture context (e.g., vulnerable monocultures; egg/brood stock I&T)
	Need to protect wild stocks/species, capture fisheries and sports-fishing
	Uncertainty concerning aquaculture/wild stock disease interactions
SOURCES	Enzootic sites/zones/areas – environment, reservoirs, vectors, carriers
	Introductions and transfers
	de novo emergence of serious AAD pathogens/strains
MODIFIERS	Regulation and control – transport, travel, trade
	Stakeholder compliance and participation
	Surveillance, testing and communication that are sound, timely and accurate
TEMPORAL EXPRESSION	Potential to occur anytime
GEOGRAPHICAL EXTENT	Potential to occur anywhere - notwithstanding "known" pathogen distribution, limitations, expression and characteristics
OUTCOMES	Economic/job losses, particularly related to seafood trade
	Limitations/restrictions/effects for all seafood sectors and many communities
	Temporary/permanent effects on species, stocks, biodiversity and ecosystems

Research needs (partnerships implicit): Research priority is high as consequence of severity of effect being high and the probability of occurrence being moderate to high. Mitigation is achievable but costly. Ongoing, targeted development/improvement of diagnostic testing is required to optimize scope, ease of use, timeliness, integrity,

accuracy, specificity, sensitivity, and cost-effectiveness (e.g., rapid tests, microarrays, pathogen characterization, biosecurity safeguards, reference test design). Ongoing, targeted research is needed of the occurrence, epidemiology, pathogenesis, and pathology of severe enzootic and exotic AADs.

Monitoring/control needs: Statistically valid AAD monitoring and sound sampling/testing are required to bolster baseline, exposure, and occurrence data.

Local aquatic animal diseases

End point: An unregulated enzootic aquatic animal disease (AAD) outbreak causes variable degrees of resource/economic loss to local watersheds and/or aquaculture sites, but poses little risk for further spread and/or unlimited persistence.

Previous experience: These local aquatic animal diseases (LAADs) are caused by pathogens that are opportunistic and/or require specific conditions (salinity, temperature, nutrients, hosts, carriers, vectors, poor husbandry) to cause overt infections/outbreaks in local watersheds and aquaculture sites. In these cases, concern about pathogen interactions among wild and cultured aquatic animal populations may focus on the ramifications of treatment regimes (antibacterial and chemical residues, microbial antibiotic resistance) rather than on local disease transmission itself. There is considerable information and experience available, such that effective preventative and control measures can often be implemented to limit/control infections and mitigate effects on local resources and cultured populations. Outbreaks/occurrences of LAADs can be unpredictable, unavoidable, self-limiting and/or subject to human mitigation. In aquaculture sites, good husbandry practices may be insufficient to prevent LAAD outbreaks, such that active control/eradication procedures are implemented, including treatment with chemicals and/or antibiotics.

Integrated management context: This end point relates to all aquatic animal resource sectors, implicating the cooperation of governments, municipalities and industry to properly treat sewage outfalls, control effluents, protect biodiversity, and implement good management procedures (GMPs), on-farm codes of practice and sound husbandry practices.

DRIVERS	Local environmental conditions; ecosystem changes; resource extraction and other human activities; poor husbandry; anti-microbial resistance
	Stressing preventative approaches, research and technology transfer to limit conditions/pathways that contribute to LAAD outbreaks
	Aquaculture context (e.g., good husbandry; sound biosecurity; responsible use of therapeutants and chemicals)
SOURCES	Any/all sites/zones/areas – environment, reservoirs, vectors, carriers
	Introductions and transfers
	de novo emergence of new L AAD pathogens/strains
MODIFIERS	Awareness, preventive measures and husbandry
	Societal commitment to sustainable development, good husbandry and communication

	Responsible use of therapeutants and chemicals
TEMPORAL EXPRESSION	Potential to occur anytime
GEOGRAPHICAL EXTENT	Potential to occur anywhere, but localized in extent
OUTCOMES	Local, often temporary, economic and/or resource losses
	Persistent negative effects on local industries and communities if underlying causes remain unrecognized and/or unresolved

Research needs (partnerships implicit): Research priority is rated medium as the consequence of severity is medium (albeit localized) and the probability of occurrence is moderate. Mitigation is achievable, but may be compromised by multiple antibiotic resistance, making disease prevention the research focus. Ongoing, targeted research to provide accurate on-farm rapid diagnostic testing is needed. Also research to better understand the growth characteristics, vulnerabilities and epidemiology of LAAD pathogens is required (to strengthen LAAD preventive measures related to human activities, biosecurity and aquaculture husbandry practices as well as helping improve disease treatment regimes).

Monitoring/control needs: Statistically valid LAAD monitoring and sound sampling/testing are required to bolster baseline, exposure and occurrence data.

BIVALVE CULTURE[17]

Marine bivalve culture, as presently practiced, is inherently different than finfish culture in that growth of the farmed organisms is dependent on the presence of natural food in the water. In addition, the economics of the industry are such that prevention is essentially the only method used for disease control. A National Advisory Process meeting on the risks associated with bivalve culture was held in Moncton, NB the week of 27 February, 2006. The peer-reviewed status report from that meeting provides the basis for this section of this discussion paper. Most of the information presented was from research on suspended mussel culture in Atlantic Canada. Extrapolation of these results to other types of bivalve culture may not be warranted. However, in general it is believed that most effects of bivalve culture are related to the relative scale of the activity rather than the type of culture activity. Compared with salmon cage culture there has been relatively little research conducted on the environmental interactions with bivalve culture operations and therefore there is greater uncertainty regarding the likely severity and probability of occurrence of most of the potential effects.

[17] DFO, 2006, "(t)he term bivalve is preferred to shellfish because in Canada most shellfish species used in aquaculture are bivalves."

Grazing of seston by cultured bivalves effecting inorganic nutrient cycling

End point: Excretion of nutrients by large numbers of cultured bivalves affects inorganic nutrient cycling resulting in changes to ecosystem components and functions.

Previous experience: When the scale of the bivalve culture activity is large relative to the ecosystem of concern, the excretion of nutrients by the cultured bivalves may affect nutrient dynamics at an ecosystem level. Increased nutrient levels and changes in the relative abundance of nutrients may promote phytoplankton production and/or alter species composition, which in turn affects the abundance and species of grazers. There is a potential for the increased occurrence of algal blooms. The effects that are ultimately observed depend a great deal upon scale and the physical and oceanographic characteristics of the system.

Integrated management context: The effect that large-scale bivalve culture has on nutrient cycling in an ecosystem must be considered in the context of other nutrient sources and sinks. Complex situations are often present in the near-shore environments common to bivalve culture sites where both land-based activities and coastal ocean processes are important in determining the effect of changes in nutrient cycling.

DRIVERS	Grazing of seston by cultured bivalves effects inorganic nutrient cycling
	Increased nutrient levels due to bivalve excretion
	Increased flux of nutrients to the sediments due to settling of feces and pseudo-feces.
	Removal of nutrients from system in harvested bivalve biomass.
SOURCES	Cultured bivalves
	Agricultural run-off
	Domestic and industrial sewage
MODIFIERS	Relative scale of culture activity to ecosystem
	Other factors limiting primary production, e.g. light
	Oceanographic processes
TEMPORAL EXPRESSION	Nutrient input from excretion will end when animals are removed from site however release of nutrients bound in sediments could continue for months or years following site abandonment.
GEOGRAPHICAL EXTENT	Relative scale is a dominant factor. When the culture operation is large relative to the size of the ecosystem of concern then effects can be at the ecosystem level. The converse is also true where effects are highly localized.
OUTCOMES	Potential significant shift in the base of the marine food web, which could cascade through other trophic levels.
	Potential uptake and removal of excess nutrients entering into the system from other sources.

Research needs: The severity of the potential effect ranges from negligible to high and the probability of an adverse outcome being expressed is largely unknown. Relative scale is critical. The research priority is therefore deemed to be moderate. Research should focus on case studies where undesired outcomes are most likely to occur to reduce uncertainty in predicting both the potential severity and likelihood of occurrence.

Monitoring needs: Systematic long-term monitoring of environmental indicators is essential to the detection of shifts in ecosystem function and /or structure. Monitoring programs have to be established to support research initiatives.

Habitat Change and Loss

Enrichment of bottom sediments with fine sediments and organic matter resulting in undesirable changes to benthic communities

End point: Enrichment of bottom sediments near shellfish farms with fine sediment and organic matter resulting in change in benthic community structure.

Previous experiences: With respect to suspended culture where benthic effects as a result of increased sedimentation have been demonstrated, most effects are observed immediately below or within short distances of the farm. However for bivalve culture in general the small amount of information in the peer-reviewed literature on effects on habitat is fragmented and inconclusive. Therefore little is known about the relative sensitivity of different types of habitat or the relative effects of different types of shellfish culture on sensitive habitats.

Integrated management context: There are many other anthropogenic and natural sources of both fine sediments and organic matter in the coastal zone. Natural sources include river run-off and decaying macrophytes.

DRIVERS	Enrichment of bottom sediments near shellfish farms with fine sediment and organic matter
	Bivalves ingest seston from the water column and excrete organically rich feces and pseudo-feces that settle rapidly
SOURCES	Bivalve culture
	Terrestrial run-off
MODIFIERS	Type of bivalve culture
	Physical and oceanographic conditions
	Sensitivity of natural habitat
TEMPORAL EXPRESSION	Enrichment is linked to culture activity so that when activity ceases enrichment will also cease and within a finite time period habitat recovery should occur
GEOGRAPHICAL EXTENT	Effects appears to be limited to the vicinity of the culture activity but relative scale is very important since the culture activity may be large relative to the habitat of concern
OUTCOMES	Changes in benthic community structure to opportunistic species or in its

	extreme development of an anoxic area
	At moderate levels of enrichment, in areas naturally limited by nutrients, benthic productivity may be enhanced

Research needs: The severity of the potential effect ranges from negligible to high and the probability of an adverse outcome being expressed is largely unknown. Relative scale is critical. The research priority is therefore deemed to be moderate. Research should focus on case studies where undesired outcomes are most likely to occur to reduce uncertainty in predicting both the potential severity and likelihood of occurrence. Development and validation of predictive models is essential to the support of informed management decisions.

Monitoring needs: In situations like this where environmental quality targets are unknown monitoring key indicators for trend over time is essential for making informed management and regulatory decisions.

Changes in physical habitat

End point: Changes in the currents and physical habitat resulting in increased occurrence and abundance of undesirable organisms.

Previous experience: The physical structures associated with bivalve culture and the cultured organisms themselves provide additional hard substrate and three-dimensional habitats that affect the presence and abundance of a wide range of biota. However it is not known if there is a net increase in productivity as a result of this enhancement. In some areas this habitat has become a favored location for invasive species. While effects are localized to the culture operation, the relative scale has to be considered when assessing the severity of the potential changes.

Integrated management context: Intense human activity of various types results in additions and changes to physical habitat in the coastal zone. Furthermore, natural processes such as erosion and deposition of sediments can result in significant changes in habitat.

DRIVERS	Physical presence of aquaculture infrastructure and physical surface of cultured bivalves
SOURCES	Bivalve aquaculture operations
	Wharves, marinas, boat moorings, and various coastal structures.
MODIFIERS	Relative scale
	Extent to which production is habitat limited
TEMPORAL EXPRESSION	Potential for effect is removed when structures are removed.
GEOGRAPHICAL EXTENT	Limited to the spatial extent of the infrastructure
OUTCOMES	Increased production of organisms that would otherwise be limited by available habitat.
	Proliferation of opportunistic species.

Research needs: When the scale of the bivalve culture activity is large relative to the ecosystem or system of interest, there is legitimate concern about the potential severity of this effect. There is little or no knowledge about the factors that affect either the severity or potential for occurrence. The further development of ecosystem models is essential to increasing our knowledge and our ability to predict. Mitigation can be achieved by keeping the scale of the aquaculture activity small relative to the size of the ecosystem but even then more knowledge is needed regarding scaling factors and appropriate management targets. The research priority is moderate.

Monitoring needs: Monitoring of appropriate benthic and pelagic indicators is essential for increasing our understanding of these effects and for making informed management decisions.

Changes in Wild Fish and Shellfish Populations

Changes in trophic resources

End point: Changes in the abundance of endemic trophic resources at the population level

Previous experience: Depending upon the relative scale of the culture operation, water column seston can be depleted by the feeding of the cultured bivalves. This has the potential for generating a cascade effect in other biota in the ecosystem. There is some limited research to indicate that such effects may occur, but the frequency with which they might occur and their severity is unknown.

Integrated management context: There is a wide range of human activities and natural events that can affect ecosystem structure and function in the coastal environment. Potential changes resulting from aquaculture activity have to be assessed and managed within that context.

DRIVERS	Natural seston depletion by feeding of cultured bivalves
SOURCES	Bivalve aquaculture operations
	Natural populations of filter feeders
MODIFIERS	In situ primary productivity
	Import and export of natural seston
	Enhancement of primary production through nutrient enrichment
TEMPORAL EXPRESSION	Seston supply will become available upon removal of cultured organisms, but changes in ecosystem structure or function may not be reversed
GEOGRAPHICAL EXTENT	Relative scale of the aquaculture activity is important but where cultured bivalve ingestion depletes the seston, an entire coastal ecosystem can be affected.
OUTCOMES	Potential significant changes in ecosystem structure and function of unknown quality, i.e. these could be deemed to be positive or negative effects.

Research needs: As already noted relative scale is very important so severity of effect could range from negligible to high. However, there is very little knowledge upon which to base predictions. The potential for occurrence is also largely unknown. The priority for research is therefore moderate to high, particularly where there is pressure to permit aquaculture operations of relatively large scale. Due to the complex nature of the interactions, modeling will be an essential component of the required research activity.

Monitoring needs: Monitoring key ecosystem indicators is essential for trend over time analysis particularly where reference points and targets are not available.

Introduction of Pathogens

The needs already identified for marine finfish culture are broadly applicable to shellfish aquaculture. However, the open, exposed nature of bivalve molluscan aquaculture differs from most finfish aquaculture regimes, such that risks and research needs are highly focused on epidemiology, including sub-clinical infections, and differential diagnostics (particularly of protozoan pathogens) to underpin monitoring, surveillance, zonation, disease control, biosecurity and especially, integrated management. Disease interactions relating to containment and escapement (as in finfish cage culture) are *non sequiturs* here.

FRESHWATER FINFISH CULTURE

There is a wide range of freshwater finfish culture activities in Canada. This section focuses on freshwater cage culture. Pond culture for "u-fish" operations falls under provincial jurisdiction. Hatchery operations, whether for enhancement or aquaculture smolt production, are regulated based on their effluent discharges.

Many of the issues surrounding freshwater cage culture are similar to those related to sea cage culture. However the potential severity of effects will be modified by environmental factors, primarily the relative scale of the fish-farm operations to the size of the freshwater ecosystems. In general there is a scarcity of scientific information on the effects of finfish culture in fresh water in Canada. This means that the uncertainty associated with the various effects, their severity, and occurrence, will be greater than that for marine finfish thus increasing the priority for research.

Nutrient Enrichment

Microalgae

End point: Increase in frequency, distribution, and nature of algal blooms affecting wild or cultured organisms, including potential toxicity to humans and/or wild and cultured organisms, effects on human activities, and the use of freshwater as a commodity.

Previous experience: Effects on water quality from fish farming are variable depending upon site-specific factors. Nitrogen concentrations are elevated only in the vicinity of the cages. Detectable increases in total phosphorus are reported at cage farms located in shallow or poorly flushed basins while no detectable changes are found at farms in deep

water or with adequate flushing. The relative scale of the aquaculture activity to the water basin and its flushing characteristics is very important. However, little is known about the cycling of phosphorus released from particulate wastes into the water column. Recent studies show little or no detectable effect of increased nutrient availability on levels of chlorophyll a farm sites and only localized effects on periphytic algae. The one reported study of pelagic bacteria indicated no increase in the abundance of bacteria but an increase in production. Trophic cascading of these effects could result in decreased water quality with negative effects on other human activities and use of the water.

Effluents from land-based facilities have been shown to increase nutrient levels in receiving waters and significant changes in primary production, epilithic biomass, chlorophyll a, algal species composition, bacterial abundance, and heterotrophic activity have been observed.

Integrated management context: There tends to be a number and variety of anthropogenic nutrient inputs into freshwater basins. Loadings from aquaculture inputs must be evaluated as part of the overall nutrient flux.

DRIVERS	Significant increased abundance of production limiting nutrients
	Changes in relative abundance of nutrients
SOURCES	Finfish aquaculture
	Agricultural run-off
	Storm run-off from urban/suburban areas
	Domestic and industrial sewage discharges
MODIFIERS	Dilution regime, hydraulic residence time
	Other limiting factors, e.g. turbidity, turbulence
TEMPORAL EXPRESSION	Input from excretion is seasonal and will cease when culture operations cease. Nutrients will continue to be released from particulate material after operations cease. Time required to reach "before culture" conditions is unknown.
GEOGRAPHICAL EXTENT	Dependent upon advection and dispersion of dissolved and particulate wastes. Also dependent on the scale of the culture operation relative to the volume and hydraulic residence time of the freshwater ecosystem.
OUTCOMES	Potential for significant increases in microbial and algal abundance, and for occurrence of harmful algal species affecting other resource users.
	Occurrence of blooms of some species has a direct negative impact on farmed and wild fish, i.e. stress and mortality
	Die-off of large blooms creates oxygen depression resulting in stress and mortality of farmed and wild fish.
	Potential for negatively affecting the use of water for other uses such a potable water supply and recreational activities.

Research needs: The scale of the effects of fish cage operations in water basins can range from local to basin wide, therefore the severity of the effects can range from low to high

and the probability of the outcome being expressed is probably moderate. However there is a lack of knowledge about the long-term fate of nutrients, particularly phosphorus, in particulate wastes. The research priority is generally moderate due to a high degree of uncertainty regarding severity and occurrence. The priority for research on the fate of nutrients in particulate wastes is also moderate.

Monitoring needs: Since there are only limited recent data available, monitoring of primary production, algal community composition, or biomass changes in the vicinity of any major freshwater aquaculture activity would provide useful information.

CHEMICAL POLLUTION

Toxic chemical levels in the environment that effect native flora and fauna

End point: Releases, accidental and approved, of chemicals on aquaculture sites result in environmental levels that are toxic to native flora and fauna

Previous experiences: There is little information on the fate, distribution, and effects of chemicals, particularly chemical therapeutants, used in aquaculture operations in freshwater systems. Chemical usage in freshwater aquaculture appears to be lower than in marine culture but environmental factors may cause these chemicals to persist longer in freshwater ecosystems. The development of microbial resistance in freshwater ecosystems is well documented, but factors affecting this are unknown. Also little is known about the effect of chronic exposure of fish and other freshwater organisms to antibiotics and other chemical therapeutants, and the fate of inorganic contaminants such as zinc and copper, which are associated with finfish aquaculture operations.

Integrated management context: Freshwater systems are often subjected to a wide range of human activities that result in chemicals entering, directly or indirectly, lakes or moving waters. While individual inputs have to be managed, the management objective must be the overall water and sediment quality of the receiving waters.

DRIVERS	Accidental and approved discharges of chemicals into the environment
	Chemical discharges from aquaculture sites
	Other local and long distance inputs
SOURCES	Fish food
	Chemical therapeutants to control and treat disease
	Domestic and industrial sewage and storm discharges
	Local and long distance industrial discharges
MODIFIERS	Advection and dispersal of contaminants
	Concentration in organically rich sediments
TEMPORAL EXPRESSION	Concern is regarding levels of persistent organic and inorganic pollutants that are not biodegradable and accumulate over time. Effects are expected to be due to chronic exposure and expressed as sub-lethal effects. Short-term acute toxicity is rare.

GEOGRAPHICAL EXTENT	Primary concern is the immediate vicinity of the site but local factors could influence focus of potential impact
OUTCOMES	Potential short-term acute toxicity on non-target organisms
	Potential sub-lethal chronic effects on aquatic organisms and populations

Research needs: Section 36 of the Fisheries Act prohibits the discharge of any deleterious substance into waters frequented by fish; therefore although the potential severity of such a discharge is high, particularly in smaller lakes, the probability of occurrence is extremely low or negligible. The need for research related specifically to aquaculture inputs is low. However as noted in the introduction to this section there is little information available on freshwater aquaculture so there is a priority for research to at least establish the scope of the problem.

HABITAT CHANGE AND LOSS

Enrichment of bottom sediments with fine sediments and organic matter

End point: Enrichment of bottom sediments near cages with fine sediment and organic matter resulting in changes in benthic community structure and function.

Previous experiences: Sediments directly beneath cages show enrichment in phosphorus, nitrogen, organic carbon, copper, and zinc. However there are few recent publications on the benthic effects of freshwater cage culture. Effects appear to be similar to those for other forms of organic enrichment, i.e. decreased taxa richness and diversity, and increased abundance of organisms resistant to sedimentation and low oxygen. There are no published Canadian studies of the recovery of sediments and benthic communities at fallowed or abandoned sites. Recovery of lotic systems can be expected to be more rapid than that for lentic systems.

Integrated management context: There are numerous human activities that release fine sediments and particulate organic matter into freshwater lakes and rivers. The aquaculture loadings need to be considered in that context.

DRIVERS	Particulate organic matter from culture operations
	Effluents from land-based facilities
SOURCES	Uneaten and waste feed
	Excretion of particulate material
	Agricultural run-off
	Domestic and industrial wastes
MODIFIERS	Advective and dispersive forces at site
	Dissolved organic matter
	Natural benthic substrate
	Density of aquaculture operations
TEMPORAL EXPRESSION	Amount and rate of accumulation is a function of site characteristics and management.

	Seasonal wind patterns can modify duration of effect.
	Site fallowing effects a return to pre-development conditions but time required is dependent on site characteristics and the extent of change.
GEOGRAPHICAL EXTENT	Build-ups resulting in benthic community change are likely limited to the vicinity of the cages. High natural variability confounds the ability to demonstrate far-field effects.
OUTCOMES	Undesirable changes in benthic community structure and function in vicinity of cages.

Research needs: Due to the localized nature of the effect, the severity of the potential change is rated as low although the probability of the outcome being expressed is high. Predictive models need to be validated for freshwater systems so that their efficacy for site selection and management can be confirmed. Research priority is moderate.

Reduction of water column oxygen to levels that are stressful to wild and cultured fish

End point: Reduction of water-dissolved oxygen concentration to levels that are stressful or lethal to fish

Previous experiences: As is generally the case, there is a lack of studies specific to Canadian conditions in fresh water. However, in general, decomposition of particulate wastes may result in hypoxia in the sediments and at the sediment–water interface. The respiration of cultured fish can cause localized reductions in dissolved oxygen levels, particularly during times of maximum growth and activity, but little effect is expected outside of the cage itself. These reductions are expected to be minor and of short duration. The biological oxygen demand associated with effluents from land-based facilities can reduce dissolved oxygen concentrations in lotic waters for short distances downstream.

Integrated management context: The input from aquaculture industry activities needs to be considered in the context of the integrated management of all inputs of BOD and COD in the water basin.

DRIVERS	Biological and chemical oxygen demand from natural and anthropogenic sources
	Relatively large-scale aquaculture operations during peak biomass
SOURCES	Fish respiration and decay of farm organic wastes
	Industrial and domestic sewage
MODIFIERS	Temperature
	Dispersion and advection
	Fish density and feeding rate
TEMPORAL EXPRESSION	Short-lived occurrence in marginal sites with high production. Condition returns to normal immediately upon removal of excessive BOD
GEOGRAPHICAL EXTENT	Localized to fish cages.

OUTCOMES	In extreme cases fish mortality
	Fish are stressed resulting in decreased growth rate and increased susceptibility to disease.

Research needs: There is considerable uncertainty as to whether or not fish farms contribute significantly to the oxygen depletion in lakes. The severity of the potential effect is high but there is uncertainty about the likelihood that the outcome would be expressed. The research need is therefore moderate.

Changes in physical habitat

End point: Changes in the physical habitat (currents and physical habitat) effecting resident organisms

Previous experience: There is no information available on the effect of the physical structures of fish farms on freshwater systems. It is likely that the situation is similar to marine fish farms but because of relative scale, farm structures in smaller freshwater systems could result in significant changes in water flow and provide a significant source of new habitat.

Integrated management context: There are numerous human activities that result in structures being placed in freshwater systems thus changing flows and producing or changing fish habitat. Effects from fish farms must be considered in the context of the cumulative effects of all of these activities.

DRIVERS	Size and number of culture systems
	Increased habitat heterogeneity
	Increase in areas for plant and animal settlement
	Changes in current velocities
SOURCES	Fish farms
	Natural erosional and depositional events
	Other man-made structures, e.g. groins, docks
MODIFIERS	Structural design
	Orientation of structures
	Placement of structures relative to currents
TEMPORAL EXPRESSION	Limited to the duration of the structures
GEOGRAPHICAL EXTENT	Proximate to the structures
OUTCOMES	Changes in the dilution and erosional schemes that result in significant changes in habitat and thence abundance and diversity of organisms.

Research needs: The potential effect is highly localized and therefore its severity is low. The likelihood that the outcome will be expressed is moderate. Research needs are

essentially the same as those directed at understanding the effects of altering fish habitat and identifying appropriate compensatory actions. Research priority is low.

Changes in Wild Fish Populations

Changes in trophic resources

End point: Changes in the abundance of endemic trophic resources at the population level

Previous experience: Freshwater cage culture generally occurs in oligotrophic waters; therefore the addition of phosphorus via aquaculture wastes to these waters may result in increased productivity of these ecosystems. The extent to which present levels of intensive finfish cage culture affect native fish populations through food web alterations is unclear. Native fish may also feed on waste feed and feces. Over time the relative amount of waste feed has been reduced dramatically through better management practices, but particulate wastes from the farms still attract native fish, resulting in increased fish activity around culture sites. The effect that this feeding has on the growth and behavior of native fish and the effect that their activity has on dispersion of wastes from under the cages are unknown.

Integrated management context: Achievement of management objectives for a water basin can only be met through the integrated management of all human activities that contribute to nutrient loading and modification of food web dynamics.

DRIVERS	Number and biomass of cultured organisms
SOURCES	Fish farms
	Changes in climate
	Effects of other human activities – man-made structures – other nutrient inputs – fishing
	Organisms that have been introduced or spread from other areas.
MODIFIERS	Degree to which tropic requirements may be supplemented by feed supplied by aquaculture.
	Human harvests
	Natural variation in the abundance of wild organisms
	Dispersion of wastes from farm site
	Aquaculture waste loading relative to ecosystem size and hydraulic residence
TEMPORAL EXPRESSION	Recovery of wild trophic resources (organisms) is dependent on the degree to which production (as opposed to standing stock) of wild organisms is effected.
	If production of trophic resources is unaffected, recovery is expected to immediately follow cessation of culture activities.
	If production has been effected, the return to historical levels will depend on recruitment and growth of natural populations. If the effected organisms are low in the food web, the recovery period is expected to be short, in the order of a year or two.

GEOGRAPHICAL EXTENT	Dependent on the distribution and intensity of culture activities in relation to the geographic distribution of the prey species
OUTCOMES	Changes in local abundance and productivity of trophic resources

Research needs: The severity of the effect is low or negligible and the probability of the outcome being expressed is low in situations where waste loading is small relative to ecosystem size and retention time. Research needs are therefore rated as low. However given the paucity of information for freshwater finfish culture in Canada research activity is warranted to provide basic information.

Changes in fitness of wild populations due to genetic interactions

End point: Significant decline in survival of native fish as a result of to genetic changes resulting from interbreeding with cultured organisms or competitive displacement.

Previous experience: There has been no research conducted in Canada on the interactions of escaped farmed fish with native fish either genetically or through competition for prey and habitat. Selected traits for farmed fish generally result in negative effects on native fish populations through predation and competition for limited resources. Results of research on the effects of rainbow trout introduced into the Great Lakes provide some indication of the potential effects of escapees from fish farms. Although reproductive success is lower, escaped farmed fish are able to reproduce with native fish in the wild. This could produce long-term genetic changes in natural populations that are detrimental. However rainbow trout accounts for the majority of freshwater aquaculture production in Canada and its potential to hybridize with naturalized populations is likely very limited.

Integrated management context: The effects of escapees need to be considered in the context of stock enhancement activities and intentional introductions of exotic species.

DRIVERS	Proportion of naturalized population interbreeding and competing with organisms escaping culture.
	Relative difference between naturalized and cultured fish genome.
SOURCES	Fish farms
	Strays from other endemic populations.
	Other introductions - Stock improvement - Transfers - Enhancement
MODIFIERS	Metapopulation structure
	Population size (effects of drift and inbreeding)
	Effects of selection by other human activities, such as fishing
TEMPORAL EXPRESSION	Where intergradation or hybridization occurs it is likely to effect at f1 generation. Effects on f2 and beyond are unclear.
GEOGRAPHICAL EXTENT	Dependent on migratory behavior and breeding distribution but most likely in

	areas adjacent to escape.
OUTCOMES	Reduced fitness of feral population.

Research needs: The severity of the potential effect is low since the only species to be affected is an introduced species. There is however a wide range of opinion on the probability of occurrence of the outcome ranging from low to high. There is also a great deal of uncertainty about both the severity and occurrence. While research priority is moderate to high, the challenge will be to identify research activities that will significantly reduce the uncertainty regarding either the severity of the potential effects or the probability of the outcome being expressed.

Monitoring needs: Monitoring the number of escapees and the occurrence of escapees and their progeny in the wild will provide an indication of the potential scale of the problem.

Introduction of Pathogens

The discussion pertaining to the introduction of pathogens in the section on Marine Finfish Culture (Salmon) is wholly applicable to freshwater finfish aquaculture.

VALIDATION

The peer-reviewed statement of knowledge papers prepared for DFO provide lists of research needs. These lists, extracted from the various papers or draft documents, are provided in Annex 2. These needs were developed in the context of gaps in our knowledge and they are identified at the project level. These lists include projects that address all of the program research needs identified in the section "Identification of Information Gaps and Associated Research Needs and Monitoring." However, for some projects listed there are no program research needs identified in this document. This is not surprising since the criterion for identifying a research need in the SOK documents was only a lack of knowledge. The research needs identified above reflect both a lack of knowledge and the need to reduce uncertainty or find mitigation since the identified end point is unacceptable.

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ANNEX 1. EXTRACTS FROM ICES REPORT

EXTRACTS FROM ANNEX 3 OF THE 2005 ICES WGEIM REPORT

The following material which provides some commonly accepted definitions for terms used in risk analysis has been extracted from the 2005 report of the ICES Working Group on the Environmental Interactions of Mariculture. Greater detail on the background and application of these terms can be found in that document. The terms used in the WGEIM report were adapted from the Australian Import Risk Analysis on Non-Viable Salmonids and Non-Salmonid Marine Finfish (AQUIS 1999). In that analysis, there are five categories of severity. The terminology used to define severity is characterized in terms of three factors: the degree of change experienced in the effected ecosystem or species, the geographical extent of the change, and the temporal duration of the change (from transient to irreversible).

DEFINITION OF SEVERITY

CATASTROPHIC	• irreversible change to ecosystems performance at the faunal province level or the extinction of a species or rare habitat
HIGH	• high mortality for an effected species or significant changes in the function of an ecosystem
	• effects would be expected to occur at the level of a single coastal or oceanic water body
	• effects would be felt for a prolonged period after the culture activities stop (greater than the period during which the new species was cultured or 3 generations of the wild species, whichever is the lesser time period)
	• Changes would not be amenable to control or mitigation.
MODERATE	• changes in ecosystem performance or species performance at a regional or subpopulation level but they would not be expected to effect whole ecosystems
	• change that has a moderately protracted consequence;
	• changes may be amenable to control or mitigation at a significant cost or their effects may be temporary
LOW	• changes are expected to effect the environment and species at a local level but would be expected to have a negligible effect at the regional or ecosystem level
	• changes that would be amenable to control or mitigation
	• effects would be of a temporary nature
NEGLIGIBLE	• changes expected to be localized to the production site and to be of a transitory nature
	• changes are readily amenable to control or mitigation

Note: the term ecosystems in the above definitions refers to water bodies of adequate size that water quality processes therein largely function independently of the processes in adjoining water bodies. For example, a bay or estuary with relatively short water residence time would not be considered an ecosystem. In contrast, a fjord or an inland sea with a protracted residence time might be considered an ecosystem for the purposes of these definitions.

DEFINITIONS OF LEVELS OF PROBABILITY

HIGH	The risk is very likely to occur.
MODERATE	The risk quite likely to be expressed.
LOW	In most cases, the risk will not be expressed.
EXTREMELY LOW	The risk is likely to be expressed only rarely.
NEGLIGIBLE	The probability of the risk being expressed is so small that it can be ignored

	in practical terms.

DECISION MATRIX

Based on the severity and probability of a risk being expressed, an explicit table that illustrates the acceptable level of risk for a jurisdiction can be constructed for making decisions (as below). A jurisdiction may decide that it is more or less risk adverse and in so doing change the values in the cells along the diagonal from lower right to upper left, i.e. the underlined vales in italics. In this particular application if the decision is to reject an effect this means that either

(a) there is sufficient knowledge to judge that the effect is unacceptable and therefore the risk must be avoided or mitigated; research may be needed, or

(b) there is a wide range of uncertainty about the potential severity and /or the probability of occurrence and further research is required to reduce the uncertainty.

Please refer to the text in the section "Science Support for Regulation of Aquaculture" regarding the application of this matrix.

		Severity				
Probability		C	H	M	L	N
	H	**Reject**	**Reject**	**Reject**	*Accept*	Accept
	M	**Reject**	**Reject**	*Accept*	Accept	Accept
	L	**Reject**	*Accept*	Accept	Accept	Accept
	EL	*Accept*	Accept	Accept	Accept	Accept
	N	Accept	Accept	Accept	Accept	Accept

Severity = C – catastrophic, H – high, M – moderate, L – low, N – negligible; Probability = H – high, M – moderate, L – low, EL – extremely Low, N – negligible; Reject = reject a request for a permit to undertake culture; Accept = accept the risks associated with permitting the culture to be undertaken

ANNEX 2. SUMMARY OF RESULTS OF RISK ANALYSIS

These priorities and needs are based on a risk analysis of the scientific knowledge regarding the hazards, the undesired end points, their potential severity and likelihood of occurrence. These priorities and needs thus identified can be legitimately modified by the socioeconomic and political risk factors.

Hazard/End Point	Regulatory Research Priority	Research Needs	Monitoring
Marine Finfish			
Nutrient Enrichment			
Enhancement of macrophyte production resulting in effects on other human activities	Low	Identification of far-field effects is hampered by the lack of baseline data and high natural variability. Mitigation is available	Pre-development data and annual surveys of peak macroalgal production
Increase in frequency, distribution, and nature of algal blooms effecting human activities or resulting in toxicity to humans and/or wild and cultured organisms	Low	Effective experimental design to study this potential effect is confounded by high natural variability coupled with a lack of definitive knowledge of the conditions that are necessary and sufficient to generate nuisance blooms.	Monitoring of coastal plankton populations at local to regional scales can provide information that is useful for site selection and for site management.
Chemical Pollution			
Releases, accidental and approved, of chemicals on aquaculture sites result in environmental levels that are toxic to native flora and fauna	Low	Mass balance models of area-wide inputs of chemicals of concern would clarify the analysis of the risk for specific locations.	Temporal trend data for a select group of priority pollutants in one or more environmental compartments would provide useful information for industry and integrated management decisions.
Habitat Change and Loss			
Enrichment of bottom sediments near cages with fine sediment and organic	Medium	Validation of deposition models is required to insure that advice on site selection is	Monitoring of benthic conditions under cages coupled with data on

Hazard/End Point	Regulatory Research Priority	Research Needs	Monitoring
matter resulting in undesirable change in benthic community structure.		reliable. Research is also needed to understand the density factor; how many farms in an embayment are too many.	site operations such as feed conversion rates, growth rates, mortalities, disease, parasites, etc. would provide the basis for much needed science advice on site selection and best management practices.
Reduction of water-dissolved oxygen concentration to levels that are stressful or lethal to fish.	Low	The cause and effects relationships are well known and the occurrence of these events is predictable.	Dissolved oxygen is a potential indicator for effects at erosional sites where any changes are more likely to be expressed in water column components of the ecosystem than in benthic components.
Changes in the physical habitat (currents and physical habitat) effecting resident organisms.	None	The probability of occurrence is high in the absence of informed site selection but low with proper site selection practices.	
Changes in Wild Fish Populations			
Significant decline in survival of wild salmon due to genetic changes resulting from interbreeding with cultured organisms.	High	The challenge will be to identify research activities that will significantly reduce the uncertainty regarding either the severity of the potential effect or the probability of the outcome being expressed.	Monitoring the number of escapees and the occurrence of escapees and their progeny in the wild will provide an indication of the potential scale of the problem.
Changes in the abundance of endemic trophic resources at the population level.	Low	It should be noted that for this hazard scale is an important factor, extensive developments in enclosed areas represent a greater hazard with greater potential severity and probability of occurrence.	
Escaped cultured fish compete with	High	There is considerable uncertainty regarding	Monitoring of the number and

Hazard/End Point	Regulatory Research Priority	Research Needs	Monitoring
native fish for essential habitat resulting in reduced fitness or competitive displacement of the native species.		both the severity of this hazard and its potential for occurring but success will be confounded by complexity of interactions and high natural variability.	location of escapees and monitoring the occurrence of escaped fish and habitat for species at risk could be an effective research and management tool.
Introduction of Pathogens			
An exotic aquatic animal disease regulated by federal legislation is introduced and/or transferred into a previously disease-free site/zone/naïve population, resulting in significant resource, economic and/or trade-related losses.	High	Ongoing, targeted development/ improvement of diagnostic testing is needed to optimize scope, ease of use, timeliness, integrity, accuracy, specificity, sensitivity and cost-effectiveness. Ongoing, targeted research of occurrence, epidemiology, pathogenesis and pathology of federally regulated exotic aquatic animal pathogens/diseases is also a priority.	Statistically valid and internationally accepted exotic disease surveillance/monitoring and sound sampling/testing are required to bolster baseline, exposure and occurrence data.
A severe enzootic aquatic animal disease (AAD), not governed regionally by federal field control measures but of "named" concern to a province/territory, becomes epizootic and/or exceeds regulatory/husbandry tolerances, in/near regional sites/zones/populations with a potential for significant resource, economic and/or trade-related losses.	High	Ongoing, targeted development/improvement of diagnostic testing is required to optimize scope, ease of use, timeliness, integrity, accuracy, specificity, sensitivity and cost-effectiveness. Ongoing, targeted research is needed of the occurrence, epidemiology, pathogenesis and pathology of severe enzootic and exotic AADs.	Statistically valid AAD monitoring and sound sampling/testing are required to bolster baseline, exposure and occurrence data.
An unregulated enzootic aquatic animal disease (AAD) outbreak causes variable degrees of resource/economic loss to local watersheds and/or	Medium	Ongoing, targeted research to provide accurate on-farm rapid diagnostic testing is needed. Also research to better understand the growth characteristics, vulnerabilities	Statistically valid LAAD monitoring and sound sampling/testing are required to bolster baseline, exposure and occurrence data.

Hazard/End Point	Regulatory Research Priority	Research Needs	Monitoring
aquaculture sites, but poses little risk for further spread and/or unlimited persistence.		and epidemiology of local aquatic animal disease (LAAD) pathogens is required.	
Shellfish Culture			
Nutrient Enrichment			
Excretion of nutrients by large numbers of cultured bivalves effects inorganic nutrient cycling resulting in undesirable changes to ecosystem components and functions.	Moderate	Research should focus on case studies where undesired outcomes are most likely to occur to reduce uncertainty in predicting both the potential severity and likelihood of occurrence.	Systematic long-term monitoring of environmental indicators is essential to the detection of shifts in ecosystem function and /or structure.
Habitat Change and Loss			
Enrichment of bottom sediments near shellfish farms with fine sediment and organic matter resulting in undesirable change in benthic community structure.	Moderate	Research should focus on case studies where undesired outcomes are most likely to occur to reduce uncertainty in predicting both the potential severity and likelihood of occurrence. Development and validation of predictive models is essential to the support of informed management decisions.	In situations like this where environmental quality targets are unknown monitoring key indicators for trend over time is essential for making informed management and regulatory decisions.
Changes in the physical habitat (currents and physical habitat) resulting in increased occurrence and abundance of undesirable organisms.	Moderate	Mitigation can be achieved by keeping the scale of the aquaculture activity small relative to the size of the ecosystem but even then more knowledge is needed regarding scaling factors and appropriate management targets.	Monitoring of appropriate benthic and pelagic indicators is essential for increasing our understanding of these effects and for making informed management decisions
Changes in Wild Fish and Shellfish Populations			
Changes in the abundance of endemic trophic resources at the population level.	Moderate	Due to the complex nature of the interactions modeling will be an essential component of the required research activity.	Monitoring key ecosystem indicators is essential for trend over time analysis particularly where reference points and targets are not

Hazard/End Point	Regulatory Research Priority	Research Needs	Monitoring
			available.
Introduction of Pathogens			
Similar to "Marine Finfish"			
Freshwater Cage Culture			
Nutrient Enrichment			
Increase in frequency, distribution, and nature of algal blooms effecting wild or cultured organisms, including potential toxicity to humans and/or wild and cultured organisms, effects on human activities and the use of freshwater as a commodity.	Moderate	There is a lack of knowledge about the long-term fate of nutrients, especially phosphorus in particulate wastes.	Since there are only limited recent data available, monitoring of primary production, algal community composition or biomass changes in the vicinity of any major freshwater aquaculture activity would provide useful information.
Chemical Pollution			
Releases, accidental and approved, of chemicals on aquaculture sites result in environmental levels that are toxic to native flora and fauna	Low	There is little information available on freshwater aquaculture in general so there is a priority for research to at least establish the scope of the problem.	
Habitat Change and Loss			
Enrichment of bottom sediments near cages with fine sediment and organic matter resulting in undesirable change in benthic community structure and function.	Moderate	Predictive models need to be validated for freshwater systems so that their efficacy for site selection and management can be confirmed.	
Reduction of water-dissolved oxygen concentration to levels that are stressful or lethal to fish	Moderate	There is considerable uncertainty whether or not fish farms contribute significantly to the oxygen depletion in lakes.	

Hazard/End Point	Regulatory Research Priority	Research Needs	Monitoring
Changes in the physical habitat (currents and physical habitat) effecting resident organisms	Low	Research needs are essentially the same as those directed at understanding the effects of altering fish habitat and identifying appropriate compensatory actions.	
Changes in Wild Fish Populations			
Changes in the abundance of endemic trophic resources at the population level	Low	Given the paucity of information for freshwater finfish culture in Canada research activity is warranted to provide basic information	
Significant decline in survival of native fish due to genetic changes resulting from interbreeding with cultured organisms or competitive displacement.	Moderate	While research priority is moderate to high the challenge will be to identify research activities that will significantly reduce the uncertainty regarding either the severity of the potential effect or the probability of the outcome being expressed.	
Introduction of Pathogens			
Similar to "Marine Finfish"			

ANNEX 3. RESEARCH PRIORITIES FROM SOK PAPERS

The following research needs have been extracted from the DFO-commissioned Statement of Knowledge papers. These research needs are based on the identification of knowledge gaps without any consideration of the priority for supporting regulatory needs. Therefore this list will contain items not covered by the research needs identified in this discussion paper. However at the same time it should contain items for all of the research needs identified in this paper. Additional SOK papers are expected to be published in the near future, i.e. 2006–07.

Far-Field Environmental Effects of Marine Finfish Aquaculture

Gaps in Knowledge

1. There is a need to determine sustainable levels of salmon production within coastal regions, inlets or embayments where marine finfish aquaculture is currently practiced in Canada.

2. Mass balance models of nutrient loading (inorganic and organic) from all sources (natural and anthropogenic) may be used to assess potential additions from finfish aquaculture. Budgets must take into account internal nutrient recycling as well as external sources.

3. General circulation models can be developed and improved to resolve combined effects of tidal and wind-driven forcing and that reflect complex topography and intertidal drying zones.

4. New methods are required to quantify processes of resuspension that redistribute fine material produced locally by finfish aquaculture sites over large areas.

5. New methods are required to quantify processes, such as flocculation and aggregation, that affect dispersion of particulate matter from finfish farm sites.

6. Studies are required to determine if the frequency and location of HAB or plankton blooms are related to the expansion of finfish aquaculture.

7. New studies are required to determine changes in water column variables in areas of intensive finfish aquaculture. In comparison to benthic studies, there have been very few investigations of changes in planktonic communities around finfish aquaculture sites.

8. Further studies are required to document environmental or ecological changes in intertidal areas and to determine if these can be linked unequivocally to the establishment of aquaculture sites.

9. Mass balance and numerical models are required to link production and external loading with aerobic and anaerobic oxidation of organic matter (pelagic and benthic), sedimentation and sulfide accumulation in sediment.

10. Further studies are required to determine the extent of far-field effects on ecological and biological impacts of antibiotic resistance induced in microbial and other wild populations in areas of intensive finfish aquaculture.

Ecosystem Level Effects of Marine Bivalve Aquaculture

Research Needs

Few studies have assessed the potential environmental interactions of the bivalve aquaculture industry, and few quantitative measures presently exist to measure the ecosystem-level effects of this industry. Research on the ecosystem-level impacts of bivalve aquaculture is currently at a relatively early stage of development compared with finfish culture and for many other anthropogenic activities. As a result, ecologically relevant studies are needed on many topics, particularly the long-term responses of major ecosystem components (phytoplankton, zooplankton, fish, benthos, as well as the cultured bivalves) to bivalve-induced changes in system energy flow and nutrient cycling.

The following general research areas have been identified to address gaps in knowledge:

1. *Ecological role of bivalve filter-feeders*: accurately quantify the density-dependant role of bivalves in controlling phytoplankton and seston concentrations, including studies of hydrodynamics, bivalve ecophysiology, and phytoplankton community and productivity responses to grazing pressure.

2. *Organic loading*: identify important processes controlling the severity of seabed organic enrichment impacts caused by bivalve biodeposits and determine the capacity of different coastal ecosystems to assimilate or recover from the effects of aquaculture-related organic loading.

3. *Nutrient dynamics*: develop a predictive understanding of the potential effects of bivalve aquaculture on nutrient concentrations, elemental ratios and rate of cycling in coastal systems, and study the consequences of altered nutrient dynamics to phytoplankton communities and blooms, including harmful algal blooms.

4. *Ecosystem structure*: investigate the effects of bivalve culture on ecosystem structure resulting from direct competition between bivalves, zooplankton and epibionts for trophic resources, and the transfer of energy and nutrients to benthic food webs.

5. *Numerical modeling*: integrate knowledge obtained on the consequences of bivalve culture on ecosystem structure and function through the use of ecosystem modeling to assess the net impact of aquaculture activities on major system

components and to address issues of aquaculture productive capacity and sustainability.

6. *Ecosystem status*: develop a scheme for classifying and assessing the state of ecosystem functioning for regions supporting bivalve aquaculture. Integrate multiple ecosystem stressors from anthropogenic land- and marine-use in ecosystem studies of culture systems.

Review of Current Practices and Possible Environmental Effects

It is clear that a number of gaps in knowledge exist for each compound or class of compound. A more thorough review of each compound would identify further specific gaps related to that chemical.

For antibiotics, there appears to be no published data collected around Canadian aquaculture sites regarding the following:

- presence of antibiotics in sediments and aquatic biota;
- presence and prevalence of antibiotic-resistant organisms in sediments and indigenous species; or
- antibiotic residues in fish and non-target aquatic organisms.

Accumulation of antibiotics in sediments may interfere with bacterial communities and affect mineralization of organic wastes (Stewart 1994), but no studies have been published in Canada.

Most work on pesticides to date has been conducted in the laboratory and has focused on determining the acute responses of aquatic organisms (non-target species) to exposure(s) to anti-sea lice chemicals. Limited field trials have focused on lethality of single treatments. Short-term responses to pesticide applications and long-term studies to establish the natural variability in local populations and measures of change in biodiversity need evaluation. Currently, commercially important non-target species have attracted much of the attention regarding effects of chemicals. There are apparently no data regarding the effects of these chemicals on microorganisms and planktonic species that form the foundation of the marine food chain in the near-shore environment. The chemical formulations of pesticide and disinfectant products have not been determined, and many of the 'inert' ingredients may be toxic to aquatic biota (Zitko 1994).

Little is known about the relationship between aquaculture and environmental contaminants such as persistent organic pollutants (POPs) and metals. Feeds may be a source of contaminants to farmed fish. Knowledge of the constituents of each formulation is required for an accurate assessment of potential risk. Metals may be deposited near aquaculture sites from at least two other sources: leaching from metal cage structures and antifoulant paints. Chlorinated compounds (Hellou et al. 2000) and metal concentrations (Chou et al. 2002) were found to be higher when the total organic carbon content was high in sediments. Wooden cages with styrofoam floats may be a source of plastic

contaminants (Zitko 1994). However, little is known about the effects of plastics on aquatic organisms.

In addition, generic gaps can be identified in relation to the scientific approach and methodology:

1. Chemical-related research is needed in all areas where marine finfish aquaculture is practiced in Canada. Research needs to be continued in New Brunswick, where scientists have a considerable database upon which to build and have the best opportunity to monitor long-term trends. In addition, work needs to be expanded in Newfoundland, Nova Scotia and British Columbia, where little such work has been conducted.

2. Toxicity data are limited to lethality tests conducted over short time frames (e.g. 24, 48 and 96 h). More work is required to determine chronic lethal and sublethal effects and the effects of realistic exposures of these compounds on indigenous species.

3. While there are laboratory-derived data on many compounds, there is almost no information regarding effects of chemicals of aquaculture origin in the field. Field surveys and experiments that investigate short-term responses to chemical application as well as long-term studies to establish natural variability in local populations and measure changes in biodiversity (and other indicators of environmental health) are needed.

4. Toxicity testing relies on single species and single compound testing in the laboratory. There is a serious lack of data regarding the cumulative effect of exposure to chemicals and the concentration and fate of chemicals of aquaculture origin. The cumulative impact of chemicals and impact of multiple exposures to non-target organisms need to be determined.

Disease Interactions between Wild and Cultured Shellfish

Knowledge and Gaps

There is little specific knowledge on the life cycle and ecology of most serious shellfish pathogens. In Canada, some effort has been directed towards understanding diseases of commercially exploited shellfish. The rapid development of shellfish aquaculture around the world, along with an increased demand for live shellfish, has escalated the need to prevent the spread of shellfish diseases. The risks associated with uncontrolled transfer and introduction of live aquatic organisms have long been recognized (Anon 1984; ICES 1988, 1995), especially for finfish species (FAO 1995; Humphrey 1995; Chillaud 1996; Humphrey et al. 1997; AQIS 1998; FAO/NACA 2000; OIE 2003a). In the last 20 years, the frequency of shellfish transfers has increased as a result of the development of hatchery-based seed production, remote setting, and the increasing use of non-indigenous species in aquaculture (Kern 1994; Hine 1996; Minchin 1996, 1999; Bartley and Minchin 1996; Elston 1996).

Introductions and Transfers

1. Lack of baseline health data for local pathogens of 'new' species under culture, may impede accurate disease risk analysis, increase the difficulty of differentiating between exotic and endemic infections, and may hinder the identification of disease management options.

2. Impacts on shellfish from accidental introduction of an exotic infectious agent could present consequences for both cultured and wild stocks under open-water culture conditions.

3. Limited ability to detect sub-clinical carriers with subsequent development of more sensitive molecular tools may expedite turn-around time for diagnosis, but detection of other potential pathogens that may be significant to wild/cultured resources will not be possible, if detection is based solely on pathogen specific diagnostic tools.

4. Lack of knowledge on the host ranges (i.e., all species susceptible to infection) for most shellfish pathogens seriously impedes the reliability of risk analysis results.

5. Increasing dependence on remote processing and live-marketing facilities, usually not equipped with treated effluent or land-based waste disposal systems, complicates assessing the risk of inadvertent spread of infectious agents.

Technological Constraints

1. Molecular tools to trace sources of infection are under development for only a few of the numerous shellfish pathogens of concern. These include probe production (Walker and Subasinghe 2000) for certain shrimp viruses (Lightner 1996b) and a few Disease oyster pathogens (Stokes and Burreson 1995; Reece et al. 1997; Berthe et al. 1999; Berthe 2000; Carnegie et al. 2000; Russell et al 2000). However, many of the procedures have not been fully validated (Cunningham 2002) and the interpretation of the results can be problematic (Bernoth 1999).

2. Focus on diagnostic assays for specific pathogens can preclude the detection of other pathogens not yet recognized because of knowledge gaps. This is mitigated through the use of histopathology, a non-specific screening technique.

3. Cell-lines routinely used to isolate intracellular pathogens of vertebrates are currently lacking for both marine molluscs and crustaceans (Mothersill and Austin 2000). This has been a significant constraint to the detection and understanding the epidemiology of viral and other intracellular microbial infections.

4. Difficulties in isolation of shellfish pathogens have also proven problematic for their culture and use in controlled infection experiments. These are necessary to examine Koch-Henle's postulates (cause-effect measures for disease) as well as accurately assess risk of establishment and disease spread (via carrier and normal hosts).

Diagnostic Sensitivity and Specificity Issues

1. The development of more sensitive diagnostic techniques has focused on pathogens that have a significant economic impact on production and trade. New pathogens, or those of more regional significance, rely on more 'traditional', but less sensitive diagnostic tests.

Recommendations

1. Research is required to allow effective development of risk analysis procedures pertaining to shellfish diseases.

2. Surveillance programs to assess the presence and prevalence of pathogens in wild and cultured shellfish in Canadian territorial waters are needed to protect Canadian aquatic resources from infectious diseases where early detection and intervention can significantly reduce impact and losses.

3. Research is needed to improve diagnostic tools especially to enhance detection capability for significant sub-clinical microbial infections.

4. Research is needed into pathogen life cycles. Information gained will be the basis of research into health management options and bolster risk analysis results.

5. Research is needed on diseases of 'new' culture species, especially those with negligible or no health information.

6. Assessment of factors associated with 'Introduction and Transfer' risks (especially fouling organisms and 'hitch-hikers') that may pose indirect health risks (e.g., as carrier reservoirs).

7. Environmental suppression/exacerbation factors associated with disease expression are notably lacking in most shellfish health literature. The impact of disease under 'new' habitats or geographic conditions requires more detailed examination.

NEAR-FIELD ORGANIC ENRICHMENT FROM MARINE FINFISH AQUACULTURE

Research Needs

Research is needed to provide an understanding of processes and to provide input to models and monitoring programs. Research is also needed to aid the scientific assessment of organic enrichment from marine finfish aquaculture (or near-field enrichment of marine finfish aquaculture).

The following specific research needs are identified:

1. Conduct sedimentology and physical and chemical oceanography studies, including coastal circulation, mixing, dispersion and transport processes in support of process models, and observation and modeling studies of water column particle dynamics.

2. Conduct seasonal studies of organic enrichment (such as redox potential and sulfide) to examine ecological factors affecting organic enrichment events from salmon farming.

3. Measure the availability of carbon to microbial decomposers.

4. Determine effects of organic enrichment on coarse and hard substrates in British Columbia where fish farms are located over mosaics of sediment types.

5. Determine effects of organic enrichment on ecosystem functioning to establish cause and effect relationships.

6. Investigate how organic enrichment from aquaculture affects benthic–pelagic coupling.

7. Undertake further fallowing studies in Pacific and Atlantic Canada.

8. Verify models, such as Lagrangian-based particle models, sediment transport models and biogeochemical models, through collaborative efforts between modelers and field biologists.

9. Predict holding capacity or assimilative limits related to the amount of local organic enrichment.

10. Develop geographical survey methods, such as satellite, aerial surveillance, underwater video photography and acoustics.

11. Devise new environmental monitoring methods.

12. Calibrate, standardize and audit existing environmental monitoring methods.

Environmental Fate and Effect of Chemicals Associated with Canadian Freshwater Aquaculture

Knowledge Gaps

1. Research is needed on the fate and effect of therapeutants in freshwater systems.

2. Research is needed to identify the causal factors controlling the distribution, accumulation, and persistence of chemicals in freshwater.

3. Research is needed regarding the factors affecting microbial resistance to antibiotics in freshwater.

4. Research is needed to examine the chronic toxicity of antibiotics and other chemotherapeutants to fish and other freshwater organisms.

5. There is a need to develop standard sampling design and analytical protocols in aquaculture science.

6. There is a need for an inventory of therapeutant usage patterns that includes reports of what is used, where and in what amount.

Cultured and Wild Fish Disease Interactions In the Canadian Marine Environment

Recommended Research

1. Gaps in knowledge on potential disease hazards should be identified early and addressed through directed research based on the principles of risk assessment in order to provide options for their management in a structured manner.

2. Baseline information on the disease status of wild stocks or a newly cultured species prior to the development of aquaculture in an area with emphasis on temporal and spatial variation would facilitate understanding of any effects that may be attributed to aquaculture.

3. When a new species susceptible to a disease enzootic in native stocks is cultured, baseline information is desirable on pathogenicity and on wild-farmed fish disease interactions. For example, nodaviruses in the family Betanoviridae.

4. More information is needed on the cause-effect relationship in the transmission of disease between wild and cultured fish.

5. Further studies are needed to objectively evaluate whether sea lice transfer between wild and cultured fish has any direct negative impact on the overall health of wild populations, particularly on the epizootiology of sea lice among Pacific salmon and its transmission to juveniles in inshore waters.

6. Rapid diagnostic tests for IHN are needed. Studies on the factors involved in virus transmission and the susceptibility of other fish species should be conducted.

7. More research is needed to understand the lifecycles of marine myxozoa, such as *Kudoa thyrsites* and *P. minibicornis* in order to develop effective prevention and control strategies.

8. Studies on water-borne disease agents or infective stages are needed to determine pathogen dispersion rates, since pathogens are frequently shed with feces.

Overview of the Environmental Impacts of Canadian Freshwater Aquaculture

Knowledge Gaps and Research Priorities

The environmental impacts of marine aquaculture are fairly well documented, but there has been little research on the environmental impacts of freshwater aquaculture in Canadian ecosystems, and extremely limited elsewhere. Research is needed in the areas listed below.

- There is need for knowledge about the factors that determine the amount of accumulation or the fate of bottom deposits in freshwater ecosystems. Information regarding current waste feed levels and feed conversion ratios at commercial freshwater finfish facilities in Canada is required to support this research.

- Research is needed to determine the impacts of freshwater aquaculture activities on benthic habitats and communities. Research is also required to elucidate the relationship between amount of waste deposition and the severity of impacts on benthic communities.

- There is limited published information, and no Canadian studies, on the recovery of sediments and sediment-associated biota after fish farming has ceased.

- Research is needed to develop an understanding of how phosphorus, nitrogen and carbon from aquaculture facilities cycle in the freshwater environment in order to determine the ecological consequences of these subsidies.

- There is limited scientific information on the impacts of aquaculture wastes on the species composition, biomass, and productivity of primary producers, microbial communities, zooplankton, or native fish populations.

- Research is needed to determine the role that native (and escaped) fish play in the removal and dispersion of phosphorus through consumption of waste feed and feces. This information will improve the ability to estimate the proportion of waste phosphorus that becomes available to affect primary production.

- Accurate estimates of the number of escaped fish entering freshwater systems are needed, as well as a determination of their role in aquatic ecosystems for all life-history stages.

- Research should be conducted on the degree and outcome of wild, stocked and farmed fish interactions.

- There is little specific scientific information pertaining to the potential or actual *genetic interactions of farmed and wild fish in Canadian freshwaters.*